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From the PM's Desk

CDR Andrew (Andy) Cibula, USN

I went out shopping for cars the other day. Now I haven't done this in a while, but not much has changed from the last time I bought a car, which was ten years ago. The salesman still tried to talk circles around me and he kept asking, "What do I have to do to get you in this car today," even though I told him repeatedly that I was just looking. But some things have changed in the last ten years. You see, I am now better trained to buy a car than I was ten years ago. That's because buying a car is a lot like buying an airplane.

The first thing I had to do was define my requirements. In my case, I wanted air conditioning—which is a must in the Washington, D.C. area. Second, I wanted anti-lock brakes—which is necessary considering the 15 feet of snow we got last winter. Third, I wanted an automatic transmission that will significantly lessen my workload in heavy traffic. These were all threshold requirements. I also put together a list of my objective requirements that included cruise control, a built-in compass to keep me from getting lost, and the Warner Brothers entertainment package that allows my kids to watch videos while driving. That one almost made the threshold list.

Once I had my requirements defined, I started on the source selection process by comparing all the different proposals against my cost and performance criteria. Needless to say, I used cost as an independent variable to drive my selection process. After all, cost is ultimately the most important parameter to me. During my source selection process, things got sticky. The problem with cars is that they have all these packages, so it is almost impossible to compare one car against the other just by using my threshold requirements. Nothing was broken out neatly, but rather all the options were packaged into odd groupings. There was the "convenience package" that included air conditioning, pinstripes, alloy wheels, mud flaps, and the electrochromatic rear view mirror. The "quick order" package included power steering, air conditioning, anti-lock brakes, cargo net, and the all-important beverage holders. Unfortunately, these packages made it almost impossible to accurately determine which car best met my requirements at the lowest cost.

So, I decided to move on to evaluate total ownership cost of the different vehicles. I calculated my average miles driven per year, times the miles per gallon, minus the number of free oil changes, times the average number of maintenance actions as determined by *Consumer Reports*, divided by the bumper-to-bumper warranty—all times the average fully-burdened labor rates of the dealer mechanic. Somewhere in all this madness I noticed a standout item in the accessory list that I thought was a standard item. It was the keyless remote entry. You know what that is—it is that little button you push to unlock the car door automatically so you don't have to fumble with your keys to unlock your cars. A certain dealer wanted $325 for this option. I couldn't believe it. Now this item didn't make my requirements list because I just thought it so basic that it HAD to be included. Every rental car I've been in the last 15 years has always had a keyless entry. As a matter of fact, the only time I remember ever seeing a car without this option was in a recent horror flick when the unlucky co-ed was being chased by a chain saw-wielding supernatural killer and got caught because she couldn't open her door. But that didn't happen in real life and neither should charging extra for a keyless entry. That's when I thought, "Boy, this seems a lot like some of the aircraft acquisition programs I'm working."

It seems as though some of the most basic necessities are having trouble finding their way onto aircraft these days. Nothing is part of a standard package. Many of those things we think should be included are now being left off for weight and cost savings. Additionally, aircraft designers offer no "convenience packages," such as a nice combination of fire fighting protection, self-sealing fuel tanks, a low-observable design, and enhanced target acquisition radars. Every survivability feature must be assessed independently against cost, weight, and performance requirements delineated in the contract. And when weight and cost run out of margin before capability, many times the capability will lose. Unfortunately for the survivability engineer, many survivability features routinely find their way to the top of the cut list.

If the aircraft design community had an unlimited weight, cost, and development schedule, this probably would not be the case. But in today's environment, more and more aircraft designers are looking for any way possible to save even a pound or two whenever and wherever they get the chance. Now, add in the fact that money is at an all-time premium, so even if weight is not an issue, cost may very well be. This tends to cause issues for those of us in the aircraft survivability business. That's because aircraft survivability designers tend to like stuff—and lots of it. In our opinion, every aircraft should have several types of IRCM and RFCM devices available, quad redundant systems for everything, titanium shielding for anything that is not quad redundant, self-sealing fuel tanks, stealth, advanced sensors complete with off- and on-board data fusion capabilities, and possibly even a pilot ejection pod capable of withstanding a direct hit from a 30-mm HEI. But, just as in buying a car, it's not always easy to get what we want and to even understand what we need.

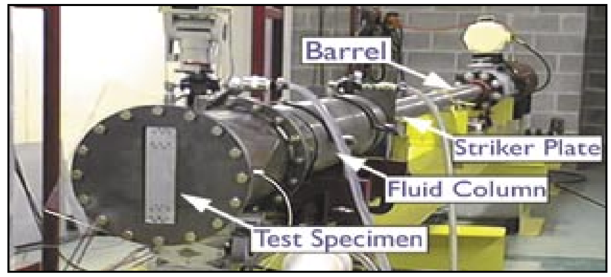
That's why this issue of the *Aircraft Survivability* newsletter is so important. Advanced survivability technology development comes in many shapes and sizes. But many of the developments in the survivability world are enhancements to maximize capability while minimizing cost and weight. Much of survivability development is not spending billions of dollars to develop stealth technology—it is developing those small affordable things, like the keyless entry that are affordable, capable, and integrated into the design. Think of those commercials during football season that advertise making things smaller, cheaper, and better—that's most of what the aircraft survivability community does. Some JASPO examples are creating enhanced modeformers that cover larger frequencies while providing better resolution using smaller electronics at a lower cost, or creating miniature stand-in jammers that can operate at a fraction of the power needed for conventional jammers,

Flexible aerogel blanket

IR imagery of Kiowa without blanket kit (left) and IR imagery of Kiowa with blanket kit (right).

but are just as effective. Another enhancement featured in previous newsletters is the advanced IR suppression blanket that weighs under a pound and can virtually eliminate excessive IR point sources.

A good example in this edition of the Aircraft Survivability newsletter is the development of the RamGun. This test fixture will never fly on an airplane (unless we are moving it to a new test site) but it is instrumental in the development of next generation aircraft. The RamGun provides the capability to test joint fixtures in a small test setup for only $25,000. Previously, large box tests were needed that cost approximately $250,000. The result—we can



RamGun

optimize joint sizing for strength and survivability, save weight, and do it at a much lower cost. This will ultimately provide the warfighter a cheaper, lighter, and more survivable aircraft.

The caveman harnessed the power of fire eras ago, but we still are not very good at modeling how it starts or propagates. Therefore, often we cannot accurately design safety and survivability features to mitigate the effects of fire and explosion. Both the fire model validation efforts and enhanced powder panels will give us a leg up on defeating the effects of fire. Powder panels are a chalky compressed panel (much like 0.125 inch drywall) that disperse firefighting agents during a ballistic impact. Many aircraft currently use this material in design, but the problem with traditional powder panels is they often release only a limited amount of chemical, reducing their effectiveness. The enhanced powder panel simply disperses more agents, but is many times more effective in fighting fires. So, for no weight increase and only a small amount of cost, we have found a way to decrease aircraft vulnerability due to fire.

Nothing is definite anymore in the aircraft design business. Every item, no matter how big or small, must earn its way onto the airplane. That is why the Joint Aircraft Survivability Program, along with other research, development, testing and evaluation activities, are working to provide aircraft designers with light, cost effective, and very capable survivability enhancements that will make a difference in the survivability and effectiveness of our combat aircraft. We recognize the limits of aircraft design, and are findings way to overcome them. So, just like buying a car—where we want the best vehicle at the best price with the safest and most reliable features—the JASPO is working with the aircraft acquisition community to provide the most survivable and effective aircraft possible. ■

CDR Andrew Cibula, USN
Program Manager, JASPO

AS News Notes

■ by Mr. Joseph Jolley

Survivability Pioneer John Morrow Passes Away

Mr. John Morrow passed away April 23, 2003, at Cottage Hospital in Santa Barbara, California. He was 71. John Morrow was well known in the aircraft survivability community, having worked in the Survivability Lethality Division and Weapons Planning Group at China Lake from 1976 until his retirement in 1997. John was the Chairman of the JTCG/AS (now JASPO) Survivability Methodology Subgroup for many years and was instrumental in getting many of the currently used survivability models accepted into the Survivability Vulnerability Information Analysis Center (SURVIAC) during that time. John also made a major contribution to the survivability of the F/A–18 aircraft, which proved its worth in Desert Storm and recent conflicts, bringing many pilots home after being hit. Mr. Morrow's vision, leadership, knowledge, and sense of humor will be greatly missed by everyone in the survivability community.

Dick Colclough Retires

Congratulations to Mr. Dick Colclough on his retirement after 48 years of distinguished service in the U.S. Air Force civil service. In his most recent assignment as Chief, Aerospace Survivability and Safety Flight with the 46th Test Wing at Wright-Patterson AFB, Ohio, Dick served as the JASPO U.S. Air Force Principal Member from June 2002 until his retirement June 3, 2003. We wish Dick the best of luck in his retirement.

Hugh Griffis—new USAF JASPO Principal Member

Congratulations to Mr. Hugh Griffis on his recent appointment as the new JASPO U.S. Air Force Principal member. Hugh had been serving as the JASPO Vulnerability Reduction Subgroup Chairman for the past two years. A new subgroup chairman has not been named as yet. Hugh is assigned to the Aeronautical Systems Center, Engineering Directorate at Wright-Patterson AFB, Ohio, and currently has important responsibilities for the survivability design of the Joint Strike Fighter and other programs.

JASPO FY04 Program Planning Underway

On May 6–8, a successful Combined Subgroup Planning meeting was held at Nashua, New Hampshire. BAE Systems hosted the meeting, where all four JASPO subgroups met in a collaborative setting to plan next year's program. The proposed FY04 projects were rated by the JASPO Advisory Group using the Web site recently completed (http://jas.jcs.mil). Final approval of next year's program took place at the PMSG meeting in Seattle, Washington, August 19–21, 2003.

JASPO Supports NASA

This past March, the JASPO attended the Aviation Security Roll-out Workshop sponsored by NASA's Aviation Safety and Security Program Office at the NASA Langley Research Office in Hampton, Virginia. The NASA project is focused on a national strategy for aviation security and development of concepts and technologies which would increase the robustness of the air transportation system against threats and hostile acts. There are four focus areas within the project—

- Aircraft and Systems Vulnerability Mitigation
- Secure Airspace Operations
- Aviation Information Screening
- Sensors for Security Applications

NASA is seeking input from other government departments and agencies in the above areas. JASPO support to the NASA initiative is in the Aircraft and Systems Vulnerability Mitigation focus area. Areas of interest to NASA include adaptive and reconfigurable controls (flight controls and propulsion), structures, fire protection, and electromagnetic hardening. NASA is planning a workshop in the fall time frame where government representatives will be invited to present their research in the above areas of interest. JASPO plans to invite and sponsor selected project engineers to present their work at this workshop. In addition to the DoD, other government agencies contributing to this NASA initiative include the Federal Aviation Administration (FAA), Transportation Security Administration (TSA), Department of Homeland Security (DHS), and the National Security Agency (NSA).

China Lake's WSL Upgraded

The Weapons Survivability Laboratory in China Lake, California, begins a new era of testing at NAVAIR's Live Fire Test Facility, MCON P–407. The inaugural test was conducted on the Pratt and Whitney JSF119 engine as part of the Joint Strike Fighter's Live Fire Test program. The facility was designed to provide a raised platform for full- scale aircraft testing, which made an ideal site to conduct Joint Strike Fighter short-takeoff-and-vertical-landing (STOVL) component live fire testing (see Figure 1).

The Live Fire Test and Evaluation Complex is nearing completion of phase I construction. Phase I consists of a 4,000 square foot control building, 45,000 gallon capacity fuel farm, AFFF and CO2 remotely controlled fire fighting capability and a 120' x 120' heat-resistant concrete test pad which is elevated 20 feet above ground level to allow for ballistic shot lines from all aspects. Phase II construction will begin this fall and will include an airflow system which will utilize the bypass airflow from nine Pratt & Whitney TF–33 engines to provide simulated flight airflow up to 520 knots over the test pad.

Figure 1. Pratt & Whitney JSF 119 engine installed on upgraded test facility at China Lake, California.

Threat Warheads and Effects Seminar

Dale Atkinson gets hands-on experience at the Threat Warheads and Effects Seminar held in Hurlburt Air Force Base, Florida, in April of this year. The seminar is an annual event co-sponsored by the Joint Aircraft Survivability Program Office. The goal of the seminar is to provide practical, hands-on training for operational personnel on the lethality of threat air defense systems and the damage they can inflict on friendly aircraft (see Figure 2).

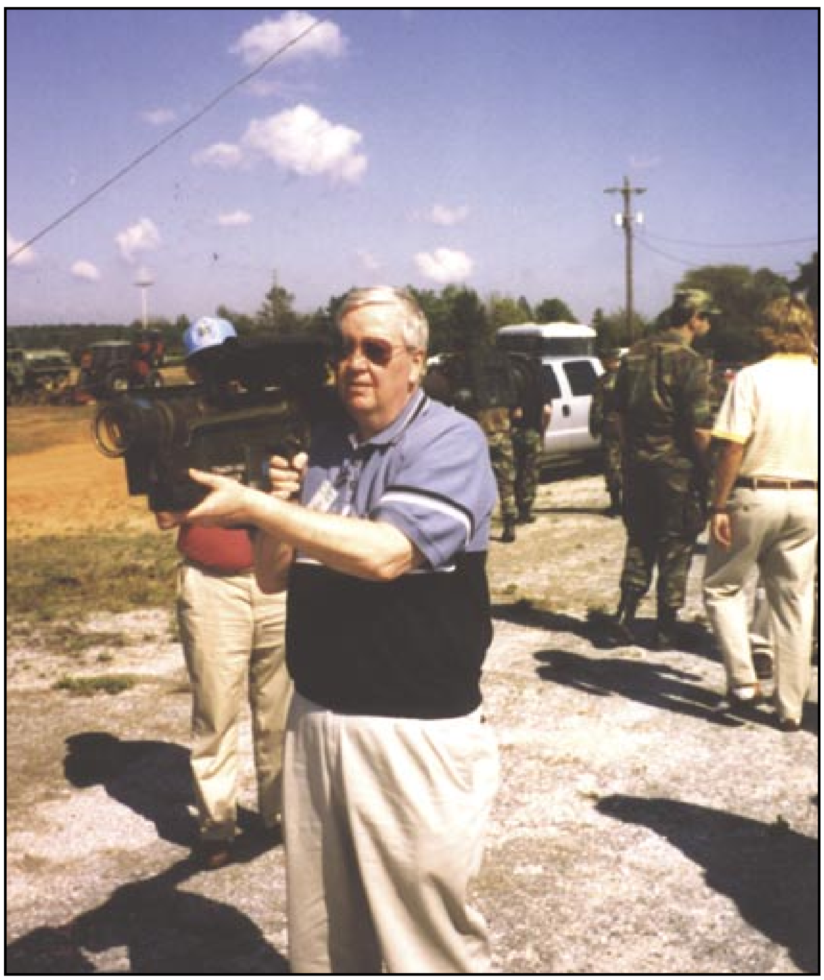


Figure 2. Dale Atkinson at the Threat Warheads and Effects Seminar in Hurlburt AFB.

Active Acoustic Cancellation for UAVs

An Aerostar unmanned aerial vehicle's acoustic signature was recently measured as part of JASP project S–2–02 "Active Acoustic Cancellation for UAVs." The Aircraft Systems Integration Lab (ASIL) anechoic chamber at Patuxent was utilized as a "quiet" box so that the UAV signature could be measured while the engine was running. The UAV was mounted on a suspended platform and rotated to measure full azimuth ad partial elevation levels. The data from this test will be used as a static baseline of noise energy and will be compared to a modified aircraft to determine the potential for signature

Figure 3 and 4 show views of the Aerostar UAV installed in the ASIL anechoic chamber at Patuxent River, Maryland.

Figure 4.

reduction. Additionally, the Aerostar will be flight tested at Eglin Air Force Base in September as part of a larger dynamic acoustic measurement exercise. The Aerostar UAV is owned by HX–21 (Rotary Wing Test Squadron) and operated by the Maritime Unmanned Development & Operations (MUDO) IPT located at Webster Field, Maryland. Jeff Brewer (brewerjr@navair.navy.mil) from the Survivability Division of NAVAIR is the principal engineer for this project and can be reached at 301.342.0202 (see Figures 3 and 4).

Miniaturized CM for UAVs

Ground and Flight testing of a miniature warning receiver was completed in February 2003 as part of JASP project S–1–02 "Miniaturized CM for UAVs." The receiver was installed in a small Aerolight UAV owned by HX–21 (Rotary Wing Test Squadron) and operated by the Maritime Unmanned Development & Operations (MUDO) IPT located at Webster Field, MD. The Aircraft Anechoic Test Facility (AATF) was used for safety of flight and receiver integration testing. The Aircraft was then flown at the electronic warfare range (ECHO) at China Lake, California, against a number of threat radar systems. The system is scheduled to undergo more flight testing later this year. Pete Bartolomeo (bartolomeopl@navair.navy.mil) and Penny Bott (penny.bott@jsf.mil) are the principal engineers for this project and can be reached at 301.342.0154 and 760.939.4247, respectively (see Figures 5 and 6). ■

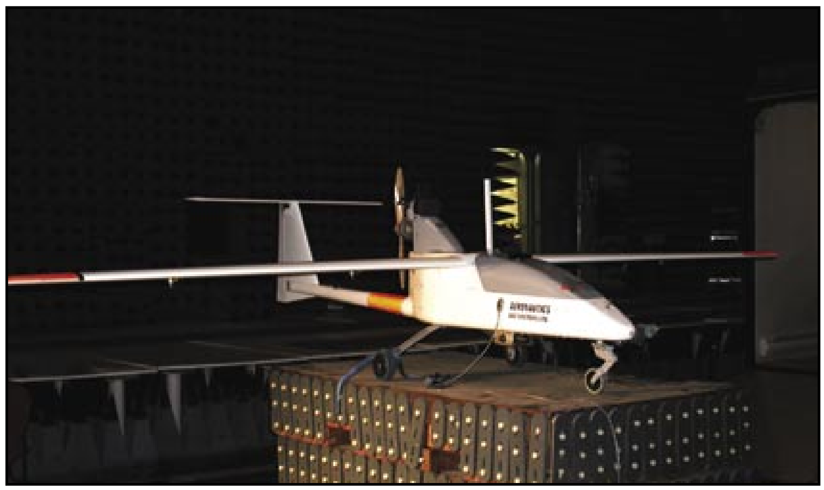


Figure 5. Aerolight UAV with a miniature receiver undergoing AATF testing.

Figure 6. Aerolight UAV being prepared for flight test at China Lake.

Laser-based Infrared Countermeasures for Both Large Aircraft and Helicopters

LAIRCM

■ by Mr. David Snodgrass

While man-portable surface-to-air missiles have been part of the modern battlefield for decades, the fact that they are now inexpensive and relatively easy to obtain makes them a very real threat to any unprotected aircraft, particularly large slower-moving craft such as cargo planes and transports.

Until recently, the most reliable method available to protect against heat-seeking missiles was the use of decoys, chaff, and flares launched to distract the missile. However, the development of improved missile target acquisition systems, coupled with the advent of sophisticated anti-decoy countermeasures, has compromised the effectiveness of these countermeasures. The Large Aircraft Infrared Countermeasures (LAIRCM) system designed by Northrop Grumman is the modern solution.

Figure 1 shows LAIRCM components—however the C–130 configuration is with five sensors not four. Figure 2 shows the C–17 configuration with three small laser transmitter assemblies not two, and has six sensors vice four and two repeaters.

LAIRCM is an active countermeasure system designed to protect large aircraft from shoulder-fired surface-to-air missiles. LAIRCM is an all-band laser-based variant of the Northrop Grumman AN/AAQ–24 (V) NEMESIS Directional IRCM (DIRCM) system currently in use by the military in both the United States and the United Kingdom. The AN/AAQ–24(V) NEMESIS system protects large fixed-wing transports and small rotary-wing aircraft from the infrared missile threat by automatically detecting a missile launch, determining if it is a threat, and activating a high-intensity countermeasure system to track and defeat the threat.

Northrop Grumman's AN/AAQ–24(V) NEMESIS system is the only IR countermeasures system currently in production that protects both large, fixed-wing transports and small, rotary wing aircraft from the infrared missile threat. The LAIRCM next-generation system introduces new improved capabilities, including a multi-band laser subsystem.

The development of the LAIRCM system was accomplished in a remarkably short period of time. In February 2001, Northrop Grumman announced that it had successfully completed all engineering and manufacturing development work and had begun production of its DIRCM program. Seven months later, in September 2001, the United States Air Force awarded the company a $66 million contract for the engineering and manufacturing development phase of a laser-based IRCM system to protect C–17 and C–130 transport aircraft, AN/AAQ–24 V–12 and V–13, respectively. The contract also included production options totaling an additional $105 million.

Less than a year later, in August 2002, the LAIRCM program successfully completed jammer effectiveness simulations, live-fire missile tests and entered low-rate initial production, all under the watchful eye of the Office of the Secretary of Defense: Director of Operational Test and Evaluation (OSD: DOT&E). "We leveraged our system off Directional Infrared Countermeasure (DIRCM) and added the Viper™ laser to protect larger aircraft and provide growth for more capable emerging missile threats," said Col. Mike Cappelano, Air Force LAIRCM program manager. "This saves the Air Force approximately $75 million and completes the first phase of the LAIRCM program 22 months faster than originally planned." The favorable milestone C low-rate initial production decision for LAIRCM was passed on August 22, 2002. "The successful milestone-C allowed

Figure 1. LAIRCMxMTRS

Figure 2. C–17

us to buy the first four LAIRCM production ship-sets for installation on four additional C–17 aircraft," Cappelano said. In December of 2002, the LAIRCM program exercised production options that allows them to buy AN/AAQ–24(V) ship-sets for an additional two C–17s and seven C–130s.

The jamming effectiveness simulations were performed at the U.S. Air Force Electronic Warfare Evaluation Simulator (AFEWES) in Fort Worth, Texas. During this test, various infrared threats were tested against a simulated C–17 in takeoff, paradrop, and landing configuration. The four month test included over 9,000 simulated engagements. The jamming effectiveness met or exceeded program requirements.

Two months after the completion of the AFEWES jamming effectiveness testing, the system went to missile live-fire testing at the Aerial Cable Range in New Mexico's White Sands Missile Range. During the live fire tests, conducted during June and July of 2002, the LAIRCM system was mounted on a cable car equipped with heat sources representing a C–17 signature, which was used as a target for surface-to-air infrared-guided missiles. The LAIRCM system successfully defeated 19 missiles shot from short, medium, and long ranges. In each of the live fire tests, the LAIRCM system was fully autonomously operated and had no prior knowledge of threat type or location. The system had to detect and declare the threat missile, then allocate the jamming assets required to defeat it.

Building on the success of their DIRCM and Viper™ laser development programs, along with the USAF LAIRCM program, USSOCOM selected the laser-based AN/AAQ–24 V(18) to protect AFSOC's fleet of MH–53s.

As the threat from infrared guided missiles continues to increase for both military and civilian aircraft, the need for active countermeasures such as those provided by the AN/AAQ–24(V) system is certain to increase as well. In response, Northrop Grumman has begun two company-funded spiral upgrade initiatives, one designed to decrease system weight, drag, and cost, and one to increase performance. These initiatives include the development of the Wanda™ lightweight low-cost pointer/tracker and the Multi-Image-Multi-Spectral (MIMS) missile warning sensor. Early prototypes of both of these spiral upgrades were live-fire tested at the Aerial Cable Range, along with the Viper™ laser, during the U.S. Navy TADIRCM tests in 1999. The MIMS MWS allows for improved detection and declaration of threats, and Wanda™ provides a more affordable, lighter-weight, lower drag pointer/tracker solution. These upgrades will help ensure the system's ability to address future IR threats while improving affordability. ■

Mr. David Snodgrass has an extensive background in the jamming of infrared missiles. Since 1995, he has worked on Northrop Grumman's Directional Infrared Countermeasures (DIRCM) and Large Aircraft Infrared Countermeasures (LAIRCM) programs. In this capacity, he leads the development and testing of the jamming waveforms and has taken part in all systems-effectiveness testing of the DIRCM system, including—hardware-in-the-loop simulations, captive seeker test flight tests, and missile live-fire testing.

Mr. Snodgrass holds a BS in Physics from Edinboro University in Pennsylvania, an MS in Particle Physics from the University of South Carolina, and an MS in Electrical Engineering from the University of South Carolina. He may be reached at David.Snodgrass@northrupgrumman.com.

Figure 3. MH–53 on desert.

MANPADS Characterization Test

Provides Modeling Data for Joint Strike Fighter

by Mr. Cliff Lawson

Man Portable Air Defense Systems (MANPADS) underscore the asymmetric nature of modern warfare—one person toting a $25,000, IR-guided missile can, in theory, destroy a military aircraft. MANPADS are everywhere. The Soviet-era SA–7, for example, is used by more than 70 countries from Afghanistan to Zimbabwe. [1]

The two primary approaches to MANPADS defense are susceptibility reduction and vulnerability reduction. On the susceptibility front, many tactics and devices are designed to evade, divert, or destroy IR-homing missiles. The Tactical Aircraft Directable Infrared Countermeasures (TADIRCM) system, for example, detects an approaching threat and disables it through the use of directed laser energy. Vulnerability picks up where susceptibility leaves off. Vulnerability reduction begins with a question—if the countermeasures don't work and the missile strikes the aircraft, what are the consequences?

To address that question for the Joint Strike Fighter (JSF) Program, "JSF Live Fire Test #08A, MANPADS Characterization Test" (LFT #08A) was conducted at NAVAIR China Lake, California. During LFT #08A, five Stinger missiles were fired and two were statically detonated against three types of targets. The test generated data that will be used for computer modeling of the MANPADS/aircraft interaction.

Designing the Test Scenario

A MANPADS missile's primary damage mechanisms were described by Dr. Al Rainis in 1998—

"[W]herever (the warhead) detonates, the explosion will produce a fragment spray that can strike and damage the aircraft. The other source of damage is the remainder of the missile body, which can strike the aircraft and has the potential to cause extensive damage." [2]

Damaged mechanisms were considered in the design of the LFT #08A targets and instrumentation. The goal was to collect data to completely characterize the dynamic missile body debris, dynamic fragment patterns, and dynamic (traveling) blast field produced by a MANPADS missile impact.

The JSF Live Fire Test Master Plan prepared by Lockheed Martin Aeronautics Company (JSF prime contractor) calls for an evaluation of the effect of a MANPADS missile impact on regions of the JSF aircraft. But while dynamic impacts against aircraft components are instructive as to the nature and degree of actual damage, the results are complex and not well suited to enhance modeling capabilities used for system design.

To generate usable modeling data to simulate missile/aircraft interaction, the three test articles selected for LFT #08A were geometrically simple—a tube, a single plate, and a series of five parallel plates. The tube configuration was used to characterize the missile fragmentation properties, the single plate was used to characterize the free-field dynamic blast pressure, and the parallel plates were used to measure blast attenuation and record the effects of the missile debris field. The data from LFT #08A will be incorporated into computer models to generate pre-test predictions for future tests.

Conducting the Test

LFT #08A was carried out at NAVAIR's Weapons Survivability Laboratory (WSL), located on the 1,100 square mile Land Range at China Lake. Previous MANPADS testing conducted at the WSL includes live Stinger firings against two F–14s, an F–16, a structural test article for a composite helicopter, and a C–130.

Hardy Tyson, a Survivability Division engineer, coordinated the design and construction of the targets, installation of the instrumentation, and conduct of the test activities.

Paul Sheridan and CDR Andy Cibula, from the JSF Program Office, Arlington, Virginia, were the sponsor and IPT Leader for the JSF Program, respectively. Contributing to the test design was Hugh Griffis, JSF Vulnerability Director at the Aeronautical Systems Center, Wright-Patterson Air Force Base, Ohio.

Figures 1, 2, and 3 (see pages 11 and 12) show the three target configurations. The targets were fabricated by WSL personnel in the laboratory's specialized machine shops. The test items were mounted between eight foot high concrete support structures to minimize the reflection of blast pressure from the ground.

The test plan called for measuring peak temperatures to within 200°F, detonation point resolution to within three inches, and missile body orientation to within three degrees. Blast pressure and force were to be recorded with a time history measured in five millisecond increments. In addition, high-speed video and high-speed film coverage (later converted

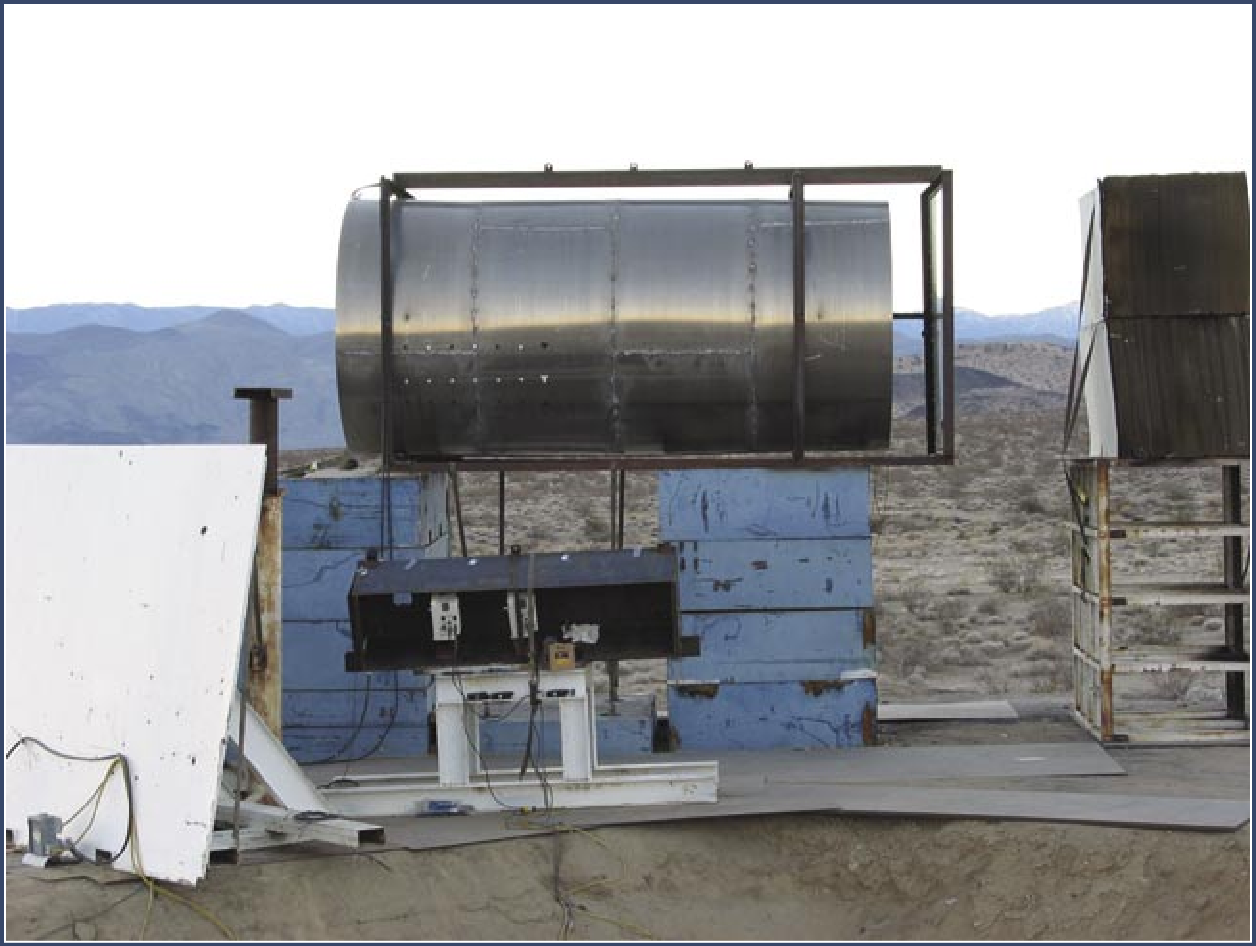


Figure 1. Test article #1: An eight foot diameter, 0.19 inch thick, 16 foot long 6061–T6 aluminum tube. A striker plate was placed two feet inside the tube to initiate detonation and capture any fragmentation vectors missed by the tube, and a witness plate was located two feet past the end of the tube. Three dynamic shots were conducted using this target configuration.

to video) were required to record the debris progression.

To gather the data, the WSL engineers and technicians installed an extensive instrumentation array for each target. The arrays included thermocouples to measure the detonation fireball, pressure transducers, and strain gauges located at various distances and directions from the detonation point. The missile velocity was determined by recording the arrival time of shock waves at two pressure transducers, in front of the target along the flight path of the missile.

Missile orientation at impact was a critical variable because the body axis had to be within a tight tolerance in order to collect valid data. Two 5,000 frame per second cameras, one positioned to the side of the test article and the other eight feet below it, captured the missile impact orientation. Two additional high-speed cameras captured missile-body-debris velocity. Engineers Chuck Frankenberger and Steve Lundin designed the setup for the digital and film recording apparatus.

Stingers were selected for LFT #08A to represent an extensive worldwide family of man-portable IR-guided missiles. With the assistance of the U.S. Army's Short Range Air Defense (SHORAD) Program Office at Redstone Arsenal, Alabama, launch services for the Stinger missiles were obtained from the manufacturer, Raytheon Missile Systems. Keith Smith from Raytheon set up the launcher at China Lake and conducted the firings.

Richard Mueller, a Survivability Division engineer, investigated several options for heat sources on which the IR-seeking missiles would home. In some previous Stinger firings at the WSL, heating elements from electric stoves had been employed. However, for the JSF testing, the test designers wanted a heat source with a more intense IR signature and low mass so that the Stinger fuze would not initiate warhead detonation before the missile contacted the striker plate. Twelve 120-volt quartz lamps were selected for the task (see Figures 4 and 5 on page 13).

The missiles were launched at two distances from the targets. By varying the range, the nominal missile impact velocities were controlled to preselected values.

As well as the five live-fire dynamic tests, two static-warhead tests were conducted, one each on target configurations two and three. Comparison of the data from the static and dynamic tests will provide additional information on velocity-dependent phenomena.

Following each test, visual and instrumentation records were reviewed. The test article was then inspected and all damage recorded and photographed. The targets were backed with Celotex panels to retain debris and fragments, and these panels were collected after each test. All instrumentation data were provided to the test sponsors and made available to other agencies and organizations.

Leveraging Taxpayer Dollars

The opportunity to fire MANPADS into specially designed targets under tightly controlled conditions with sophisticated instrumentation doesn't come along every day. Leo Budd, a Survivability Division engineer, encouraged other programs to "piggy back" on the LFT #08A test and coordinated their participation in the test activities.

Figure 2. Test article #2: An array of pressure transducers behind an eight foot by eight foot by 0.19 inch 6061–T6 aluminum striker plate. One dynamic test and one static test were conducted with this configuration.

Figure 3. Test article #3: Five parallel eight foot by eight foot test plates spaced two feet apart and mounted in a support frame. Three dynamic tests were conducted with this configuration. One test used 6061–T6 0.19 inch aluminum plates; the two remaining tests used combinations of aluminum and steel plates of different thicknesses.

Bell Helicopter, which helped sponsor the test, was an active participant in the planning phase and also provided test instrumentation. Bell will use the data to support vulnerability analyses of current and future rotary-wing aircraft.

Susceptibility and vulnerability reduction intersected at LFT #08A when the Navy Research Laboratory (NRL) set up sensors from an AN/AAR–47 missile-warning system to record data during the Stinger firings. NRL also employed a TADIRCM missile-warning subsystem during the tests. At the conclusion of LFT #08A, NRL reported highly successful data-gathering for both systems. Other developmental programs with an interest in launch detection and other MANPADS issues also set up items of equipment during the course of the testing.

Continued Testing

JSF Live Fire Test #08A, MANPADS Characterization Test, was the first of three test programs that will assess JSF vulnerability to MANPADS. A tremendous amount of data was generated, and test participants plan to hold working-group meetings as the data is evaluated and used to construct the products necessary for modeling applications. Future JSF survivability testing will seek to identify potential structural and flight-control failures that could be precipitated by a MANPADS strike. ■

Figure 4. Twelve 120-volt quartz lamps served as a low-mass heat source for the Stinger missile.

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Figure 5. Three frames from a 5,000 foot per second camera showing a Stinger warhead detonating inside test article #3.

MANPADS Analysis Methodology Development

■ Mr. Alex G. Kurtz, Dr. Ronald L. Hinrichsen, and Dr. Monty A. Moshier

Man Portable Air Defense Systems (MANPADS) have become a prevalent threat to both military and civilian aircraft. In recent conflicts, it has been proven that aircraft have survived MANPADS encounters. Some MANPADS missiles also failed to detonate on or within the aircraft. The survivability/vulnerability aircraft analysis community is beginning to understand the critical issues relating to the impacts of MANPADS missiles with aircraft. However, the community still requires a validated set of analysis tools to handle this threat. In recent years, a series of aggressive multi-year programs have been initiated to address these voids. These programs have incorporated parallel efforts that integrate first principle, high-fidelity, nonlinear structural analysis codes, test data, and analytical/empirical penetration equations to advance the state-of-the-art in vulnerability analysis techniques and understanding of aircraft-MANPADS encounters. This article presents an update of a first principle, high-fidelity MANPADS methodology development project.

The main objective of these efforts is to advance aircraft vulnerability assessment and predictive methodologies for missile encounters. Specific objectives are to—

1. Apply advanced finite element/finite difference structural analysis codes to the body-on-body penetration problem and analytically predict missile velocity, missile position, penetration depth, degradation of aircraft structure, and missile kinetic energy as a function of time.
2. Develop algorithms to include warhead blast, fragmentation, and debris effects in modeling MANPADS missile encounters with aircraft structures.

The 46th Test Wing, Wright-Patterson Air Force Base, Ohio, through its contractor, RHAMM Technologies, LLC, is responsible for these high-fidelity MANPADS methodology development projects. They have built and obtained finite element and computer aided design (CAD) aircraft models and fabricated one finite element analysis (FEA) MANPADS missile model and are in the process of developing another. The MANPADS missile finite element model was constructed in detail and is comprised of discrete sections of an actual missile (seeker, warhead, guidance and control, and motor). The MANPADS missile model also contains detailed data on section geometries, exterior dimensions, joint construction, joint strength, component construction, material properties, mass properties, and rocket motor case strength. The FEA uses high fidelity physics-based structural analysis algorithms which account for the material densities and non-linearities as well as failure strengths and/or strains of both the MANPADS and target. An explicit time integration scheme is used to solve the equations of motion of the bodies as they make contact, interact, fail, and move. Figure 1 shows the model of the MANPADS and a snapshot of a MANPADS impacting an aircraft component.

The most recent work has been focused on properly modeling the blast and fragmentation of the warhead. A coupled fluid-structure interaction technique has been chosen for this purpose. In this technique, the explosive and surrounding air are modeled as fluids while the MANPADS and target are modeled as structures. The key issues in this technique are modeling the explosive moving with the missile, modeling the fragmentation and ensuring accurate pressure pulses. Figure 2 (see page 15) presents a collage of how these issues are being resolved. The three images on the left show a generic warhead structure (dark blue) traveling through a multi-material fluid (red is air, yellow is the explosive, and light blue is water). The two images on the right show

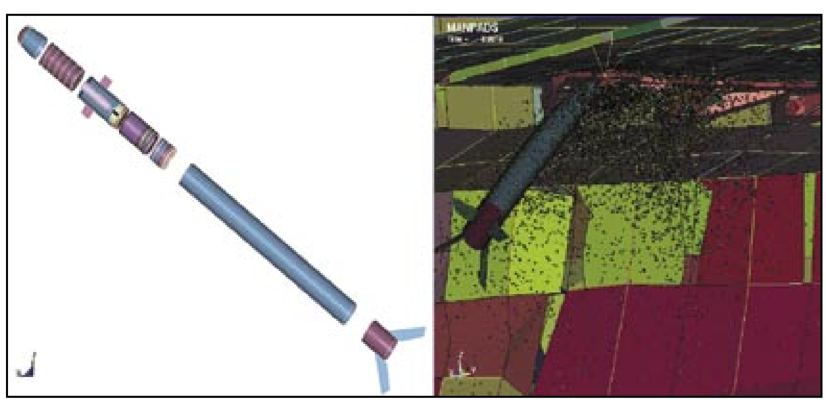

Figure 1. MANPADS striking aircraft target.

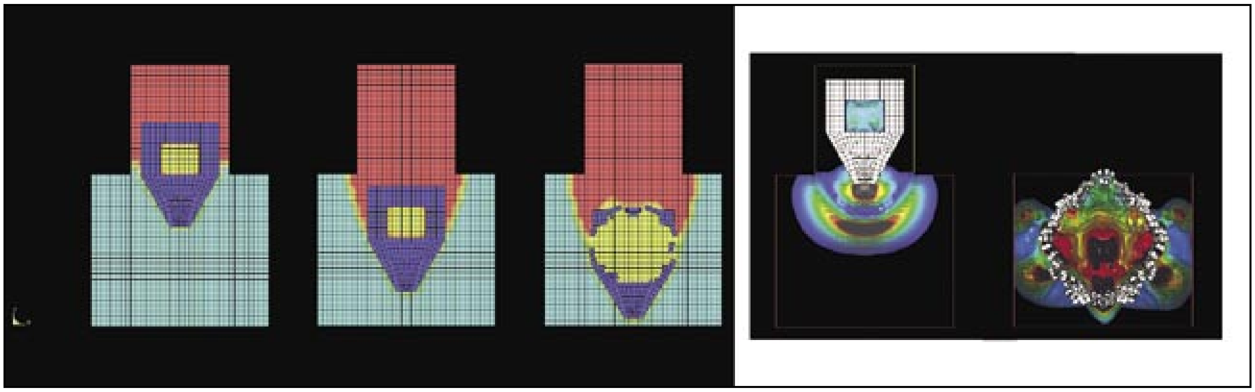

Figure 2. Collage of plans for implementing warhead blast and fragmentation

pressure isosurfaces resulting from the impact with the water. The final image shows the explosive detonating and fragments flying.

Testing is critical to credible modeling and simulations (M&S). Joint Live Fire (JLF) is not chartered to conduct validation and verification (V&V) of the analysis codes; however, when opportunities were presented, the MANPADS analysis development programs have augmented JLF tests to extract very specific data. This took the form of camera placement/speed, additional strain gauges, additional blast gages, and additional accelerometers specifically placed to augment recent or future analysis. Data was used to verify both missile breakup and aircraft damage. Another way the programs are conducting incremental V&V is to run pre-test predictions for future MANPADS tests. Following the tests, the code developers and test engineers meet to discuss test/analysis results, anomalies, and data voids.

To ensure credible MANPADS modeling and simulation methodology development, 46th Test Wing, and RHAMM Technologies, LLC, collaborate together to ensure that the simulations, multiple tests and analysis programs are completely integrated. ■

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PRISM helps the FBI Keep Aircraft Safe from MANPADS

■ by Ms. Linda Lou Crosby

Shoulder launched, infrared guided, Man Portable Air Defense Systems (MANPADS) are a significant threat to the safety of commercial aircraft. Shoulder launched terrorist attacks that threatened aircraft have occurred around the globe. Such an incident was initially suspected (although later discounted) during the investigation of the crash of TWA Flight 800 in 1996.

Leo Budd, a NAVAIR survivability engineer, said—

"Anywhere in the world where military or commercial aircraft take off or land, the Portable Resource for the Investigation of Suspected MANPADS (PRISM) system can identify locations where MANPADS could be launched toward aircraft or PRISM can be used to investigate suspected MANPADS related incidents."

Recently when he addressed the successful Weapons Division development of PRISM, a CD-based investigation tool to deal with an ever-increasing MANPADS threat.

According to Allan Wearner, head of the Systems Vulnerability Branch, the PRISM system was initially developed as a result of the support NAVAIR provided for the investigation of TWA Flight 800's fatal accident off Long Island. He said—

"A small team of engineers from China Lake were requested by the National Transportation Safety Board (NTSB) and FBI to inspect recovered aircraft debris to help determine the cause of the loss of this aircraft."

Wearner explained that aircraft vulnerability is what happens to the aircraft and its sub-systems once it is hit. MANPADS testing at China Lake's Weapons Survivability Lab and the surrounding larger land ranges have provided lessons learned for reducing vulnerability of new aircraft designs currently in the acquisition phase. The test data also allows more accurate information for threat modeling and simulation.

Having previously worked with the FBI and NTSB, NAVAIR China Lake proposed development of a computer-based information system that is readily available in the form of a compact disk that investigators can use as both a training tool and an investigative tool. This task was initially funded to develop a prototype system that had already been delivered.

The FBI funded an update to the prototype to include threat launch envelopes used for both forensic investigation and for determining airport security zones for 80 airports. These zones were plotted by a flight path threat analysis simulation provided by the Missiles and Space Intelligence Center (part of the Defense Intelligence Agency) in Huntsville, Alabama.

How it all works

The FBI wanted to be able to pull together relevant information at a crash site where a missile might have been involved. This reference material would include airport geography, flight paths, forensic information, and photographs of MANPADS, and MANPADS-related damage to aircraft to compare with damage at the crash scene.

The FBI turned to NAVAIR WD and Pacific Northwest National Laboratory to make this system a reality. The goal was to assist FBI and NTSB field investigators in conducting planned, coordinated, and "legally sufficient" searches to locate physical evidence and witnesses to an aircraft crash that may have been the result of a MANPADS attack.

Bob Sibert, of the FBI, explained—

"The PRISM system project is an ambitious undertaking. It will provide an unclassified resource that will assist field investigators with the identification of physical and trace evidence. Specifically, PRISM will provide the investigator with information about where to look for evidence of a missile strike and what to look for."

MANPADS, like the American Stinger and Russian Grail, are increasingly available for purchase in the Middle East, Western Asia, and Eastern Europe. They can provide the means for highly effective attacks on ascending and descending aircraft beyond the security zone of an airport.

Because of FBI interest and the Office of the Secretary of Defense initiatives regarding MANPADS threats to aircraft and the need to test vulnerability of aircraft to these threats, the live fire test community initiated several actions.

The Institute of Defense Analyses proposed that the initial test thrust should concentrate on dynamic missile firings into static aircraft as the best value for the effort expended. NAVAIR China Lake conducted a series of these tests to gather vulnerability data.

Figure 1. Damage from a live-fire test held at the Weapons Survivability Lab at China Lake shows the type of damage that can happen to an aircraft from a shoulder launched weapon. During this test, an F–14 was hit by a Stinger missile from a distance of one mile.

Richard Mueller, formerly in the Survivability Division, added—

"Since the PRISM prototype was first built, there have been multiple MANPADS tests on the land ranges. The knowledge and data gathered from those tests have contributed greatly to providing a solid database of information to help us better deal with MANPADS threats."

Instant access

How would field agents be able to have instant access to the PRISM solution? The decision was made to create a portable resource that could be used to help analyze possible missile attack situations by bringing to the crash scene reference material that usually takes days or longer to collect. PRISM provides reference information on flight paths, MANPADS characteristics, forensic evidence, and whatever is needed to determine exactly what happened. This includes what to look for at a possible launch site like scorched earth from a potential firing area.

The data also includes what to look for at the actual crash site, and a database of experts to contact to get further information in appropriate subject matter areas.

Other information on the PRISM CD-ROM includes photographs of types of aircraft damage, what the damage would look like if the aircraft had been hit specifically by a MANPADS and forensic analysis data on possible propellants used (see Figure 1).

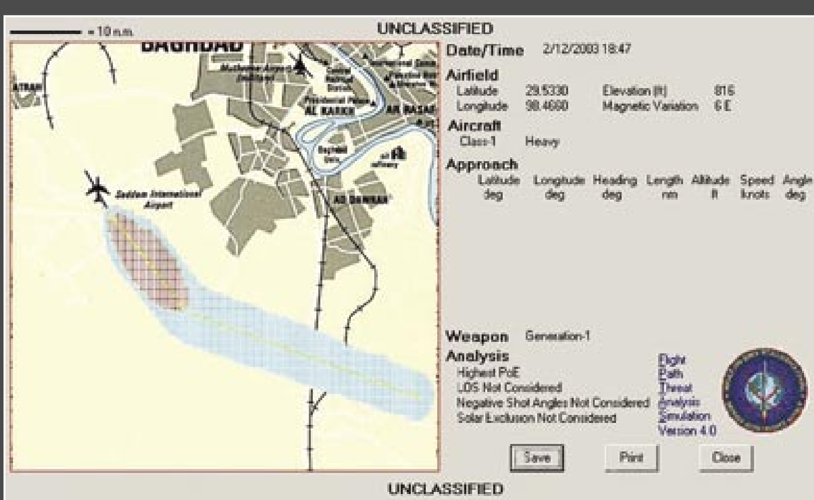

Figure 2. PRISM Threat Footprint

An aircraft crash site is a chaotic place. However, it can be treated much as any other crime scene, because the evidence is present in the bent metal.

The same basic rules for conducting any criminal investigation apply. Additional evidence can also be located along the aircraft flight path or at a possible launch site.

Mr. Budd added —

"Investigations are time critical. Responding agents need to be able to quickly generate the data needed to determine if an incident was, in fact, terrorist related."

PRISM tools can also be valuable to deployed military forces, helping to increase the safety envelope during operational efforts. ■

Ms. Linda Lou Crosby holds a Bachelors degree in Journalism and Broadcasting from California State University, Los Angeles. She has worked in the field of news and documentaries for public television for several years. Ms. Crosby is a former employee of NAVAIR at the China Lake site from 1985 to 1998. She now works for Advanced Engineering Services, formerly Veridian, in the area of strategic communications. She may be reached at 760.499.5700.

Fragment-Target Flash Experiments

for the Validation of the Fire Prediction Model (FPM)

■ by Dr. R. Reed Skaggs and Ms. A. Canami

A parametric study of ballistic threat-target impacts has been conducted to investigate the fundamental physical interactions that influence fires. The obtained data is documented here and is currently being compared with predictions from a physics based simulation model known as the Fire Prediction Model (FPM). [1]

In order to provide major improvements to the safety and survivability of combat vehicles from potential fire and explosion events, a physics-based model is being developed to accurately simulate the various stages of ballistically-induced fires. To develop such a model, the governing physics and chemistry of fuel fire ignition and sustainment must be understood chemically and physically, as well as validated. The objective of this article is to describe and document the experiments that have been performed and which will provide data for validation.

To date, there exist a number of test and evaluation studies of various fuel tanks completely filled with fuel and subjected to ballistic attack. Most of these tests were conducted for diesel-type fuels (e.g., DF2) and overmatching threats. Unfortunately, most previous studies have not provided all the necessary detailed quantitative data upon which to build chemical and physical representations that accurately describe and predict the potential for ignition and/or sustained fires. The lack of data is attributed to the fact that a ballistically induced fire is a complex event that involves almost simultaneously a complex hydrodynamic event along with rapid fuel/air mixing which interacts with an energetic ignition source over a micro-to-millisecond time duration.

The FPM, which is currently being developed, simulates a ballistically induced fire based on a single threat through a compartment bay and fuel tank, and results in threat-target interactions, hydrodynamic ram, fuel thermodynamics, and combustion processes, and ultimately computes the probability of fuel ignition and fire sustainment. Each experimental study is being simulated using the FPM to obtain predictions for comparison to the experimental data and will be reported in the near future.

The current methodology for fire ignition involving high-speed fragments is thought to be caused by the high-temperature flash that develops on the back face of the striker plate (exterior vehicle skin) immediately located prior to the fuel tank wall when fragment penetration occurs. This article describes experiments using fragment threats against both metallic and nonmetallic target materials in order to develop a database of fundamental physical validation data to assess the current methodology.

Experimental

The experimental arrangements were constructed to provide controlled conditions along with the capability to measure most of the basic physical and phenomenological changes that occur due to threat-target interactions over a very short time scale. The experiments were accomplished by constructing an armored experimental arrangement with an empty fuel tank simulator that has the capability of supporting most material types along the shotline, and could be repetitively subjected to various ballistic threats and diagnostic techniques. The fragment is a 207 gr (13.41 grams) MIL–STD fragment-simulating projectile (FSP) that is the shape of cylinder with a double-edged tip and a (L/D) that is just less than one. Two experimental series with the FSP were conducted—

1. Primary impact flash
2. Secondary impact flash

In both experimental series, the FSPs encountered different combinations of material type and thickness. The interactions were characterized for material damage holes, displaced material weights, and residual fragment masses. In addition to the physical data, the flash intensities and durations were optically measured. A minimum of three FSP firings were conducted for a given material except titanium where only one firing could be conducted due to limited supplies. For each experimental series, 0.125 inch thick 7075 aluminum panels were evaluated which served as a baseline material for each series.

Primary Impact Flash

The initial series of FSP firings were designed to quantify the phenomenon of the initial impact flash when the FSP interacts with the front surface of the fuel tank in the arrangement displayed in Figure 1 (see page 19).

The FSP was launched from a 50-caliber remotely fired gun at approximately 3,280 feet per second (1,000 meters per second). The tested fuel tank panel materials were 0.125 inch thick 7075 aluminum, 0.125 inch thick steel, 0.125 inch thick nylon, and 0.125 inch thick polyethylene. The launched fragment travels through a custom-made velocity chronograph to measure the fragment impact velocity. The

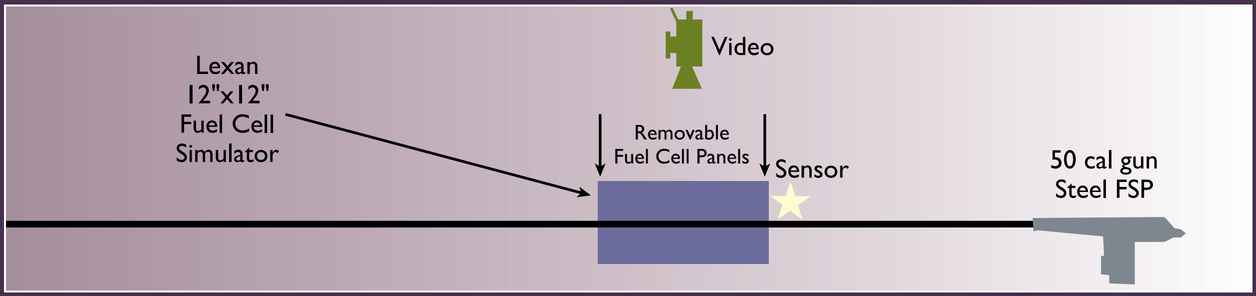

Figure 1. Experimental arrangement for fragment studies with fuel tank simulator fixture.

distances from the gun muzzle exit to the first velocity monitor, second velocity monitor, and the front panel of the fuel tank simulator were 10.15, 13.65, and 15.58 feet (3.09, 4.16, and 4.74 meters) respectively. When a ballistic threat such as the FSP perforates the fuel tank panel materials in the previously mentioned experimental arrangement, a significant amount of energy is transferred from the threat to the target. The threat-target interaction causes the target to eject fine fragments that react very energetically causing a flash phenomenon. To measure the flash intensity and duration optically, a 15 mm^2 active element, fast photo detector was utilized (Centrovision, Inc. OSD5–5T). The photodiodes are suited for low light level applications over wavelengths covering 430–900 nanometer with rise times of nine nanoseconds. The photodiode sensor was positioned perpendicular to the shotline at approximately 6 inches (15.24 cm) from the impact point. In addition, a standard video camcorder (30 feet per second) positioned approximately eight feet above the experimental apparatus recorded the entire experimental apparatus and flashes were measured. Figure 2 shows an example of characteristic intensity traces for aluminum and steel panels.

The intensity time traces were analyzed by calculating the total area under the curve from the baseline, the peak intensity (maximum deflection from the baseline), peak intensity time location, and the profile half width at the half maximum. Evaluating the intensity profiles at the half width/half maximum creates a consistent evaluation location for each profile which can sometimes be incomplete.

As seen in Figure 2, the intensity versus time traces express different flash profiles based on material types and the flash temperatures can be estimated based on the Stefan-Boltzmann law. However, initial experiments observed that the flash intensities from the sensors and recorded video would vary depending on the impact velocity of the FSP (i.e., higher FSP velocity-brighter, longer flash). This observation might be attributed to greater kinetic energy being delivered to the target at higher velocities, which in turn could result in a change in the rate at which ejected particles burn and react. Thus, the impact velocity probably needs to be accounted for when determining temperature. One approach that is being investigated is to assume that the flash acts as a broadband fluorescence source resulting from plastic deformation, vaporization, and rapid heating of target material. This assumption further presumes that the intensities obey a power law: $I \sim v^n$, where v is the impact velocity and n=8. From these assumptions Baird, et. al., [1] state that impact flash intensity can be related to temperature via: $T=v^2/24Nk$; $I=[ø/(24Nk)^4]v^n$ where N=number of atoms per unit mass, k=Boltzmann's constant, ø=Stefan constant, v=velocity, and n=8. At this time these relationships are being investigated with an experimental calibration series to determine the most appropriate method for converting the obtained intensity data into temperature values.

Thus to illustrate the responses and measured trends for the observed flashes from the target materials, the intensity data will be presented. To account for both the flash intensity and duration differences for each studied material, the integrated intensity values were divided by the half width at half maximum values to give a normalized intensity. For each experimental series, the normalized intensities were then divided by the average normal intensity value for the 0.125 inch 7075 aluminum panel investigated. The reported

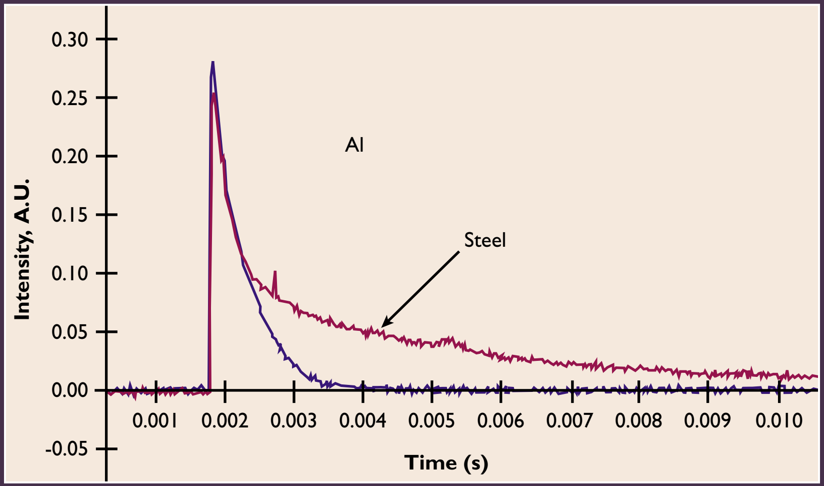

Figure 2. Representative intensity versus time traces captured by photo detectors at front surface of aluminum and steel target materials.

flash intensity durations from the photodiode sensors were determined by multiplying the half width/half maximum values by two. In addition, the photodiode intensity durations and the video flash durations do not correlate because of time and spatial response/sensitivity differences. Hence reported here are the individual sensor(s) and video durations, then averaged together to give an "average" value to evaluate material trends based on flash duration.

Secondary Impact Flash

The second series of fragment flash experiments was conducted with a slightly different configuration as shown in Figure 3. This arrangement was constructed to physically separate the back flash from the first encountered panel to the flash on the front of the second panel. In Figure 3, the fuel tank simulator from the primary impact flash studies is replaced with a panel support fixture that is a 12" x 30" (30.48 cm) rectangular box with removable entrance and exit panels. The panels were 0.125 inch thick 7075 aluminum, 0.0625 inch thick 7075 aluminum, 0.0625 inch thick 2024 aluminum, and 0.0625 inch thick titanium. To increase the fragment velocity for this series of experiments, a 30 mm gun barrel was utilized to launch the FSP at two

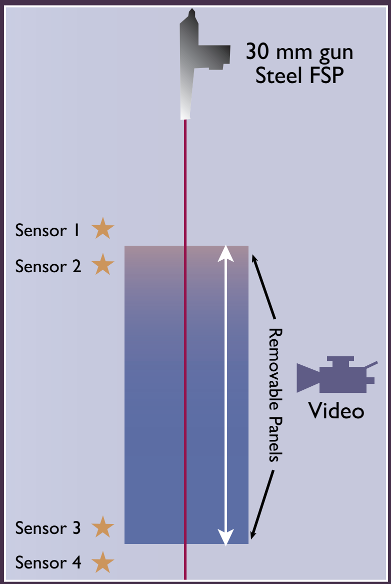

Figure 3. Top view of experimental arrangement for fragment studies of secondary impact flash phenomenon. The intensity data reported here was recorded from sensor 3.

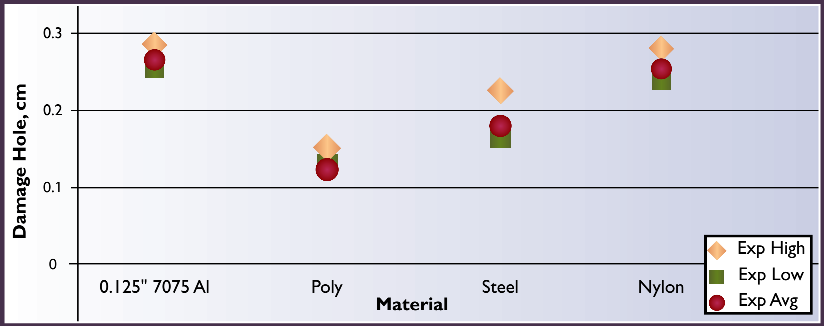

Figure 4. Entry fuel tank damage holes for primary impact flash fragment studies.

velocity regimes of 3,000 and 6,000 feet per second. The distances from the gun muzzle exit to the first velocity monitor, second velocity monitor, and the front panel of the fuel tank simulator were, respectively, 5, 6.64, and 13.02 feet (1.52, 2.02, and 3.96 meters). The flash intensity and duration were measured at four locations along the shotline using four fast photo detector(s). The photodiode sensors were situated perpendicular to the shotline at an average of 14.875 inches (37.78 cm) from the impact and penetration locations. The overall threat-target interactions were recorded with a standard video camcorder (30 frames per second) positioned approximately eight feet perpendicular to the shotline.

Results and Discussion

The damage hole data presented here for a given material data set are typically shown as the experimental high and low values and a calculated overall average value. The high and low values are individual values taken from a series of separate firings to give a perspective of the scatter experienced for a given material. The calculated average value data are averaged over a minimum of three trials. Each material, except titanium, was fired a minimum of three times. The most studied material was the 0.125 inch 7075 aluminum, which was fired at least eight times per experimental series. For the intensity data, the high, low, and average relative normalized intensities are presented while the flash durations are the average values of the photo sensor(s), the video, and the average of the two measurement techniques.

Primary Impact Flash

The average FSP velocities for the primary impact experimental series were 3221.3, 3202.5, 3183.1, and 3120.4 feet per second (981.8, 976.0, 970.1, and 951.0 meters per second) for aluminum, steel, nylon, and polyethylene materials respectively. Figure 4 presents entry fuel tank damage hole sizes.

The data in Figure 4 does not reflect the intuitive trend for nylon whose average value, 2.62 cm, was expected to lie between those for polyethylene and aluminum based on material and mechanical properties. This observation might be attributable to nylon's observed brittleness. Otherwise, the polyethylene and metal materials indicate damage holes of 1.27–1.84 cm. The data demonstrates small variations, indicating good repeatability and similar trends for the materials were also observed for the amount of material lost (ejected). The displaced material propagates as burning/reacting particles, which in turn affects the flash measurements since the particle "cloud" composes the flash. Figure 5 (see page 21) presents the experimental relative impact flash intensities, which do not necessarily follow the damage hole data in Figure 4.

The data in Figure 5 indicates that the relative flash intensities decrease for polyethylene and nylon by 30 percent and 40 percent when compared to the aluminum and steel values. The data implies that the flash intensities vary with material type where, coincidently, the higher density metal materials have higher intensities. The flash durations are presented in Figure 6 (see page 21).

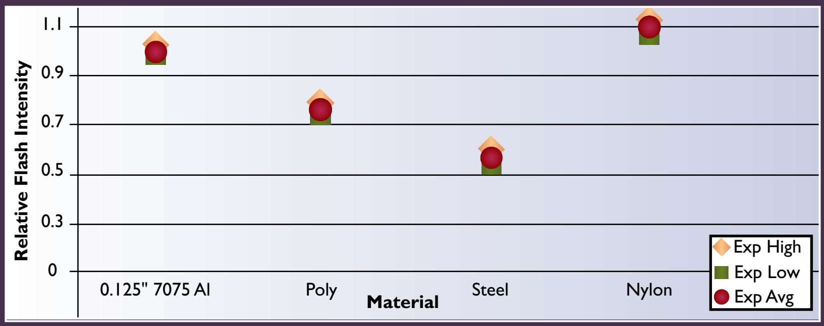

Figure 5. Relative primary impact flash intensities.

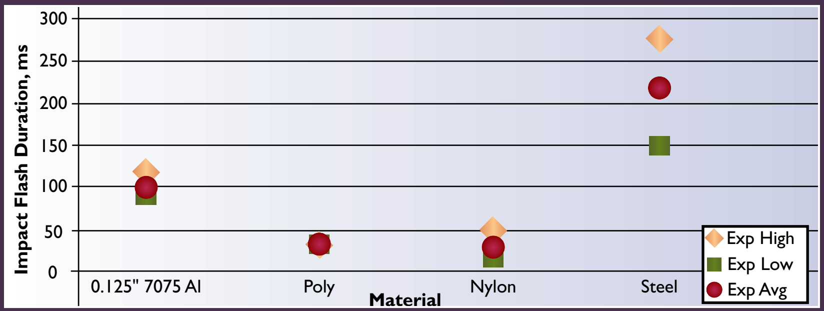

Figure 6. Primary impact flash durations.

As anticipated based on the flash intensity observations, the experimental flash durations are longer for the metallic materials than for the non-metallic materials.

Secondary Impact Flash

Evidence that the impact of a FSP on the front of a target creates an initial energetic flash lends itself to further analysis of the threat after it passes through the primary target and interacts with a secondary target surface, and hence, a secondary flash phenomenon. The experiments for secondary impact flash captured the entry and exit panel material damage holes, displaced material weights, residual fragment weights, as well as flash intensities and durations at the front and back of each encountered target panel along the shotline. The impact velocities were either 3,000 feet per second or 6,000 feet per second for the target materials of 0.0625 inch thick 2024 aluminum, 0.0625 inch thick 7075 aluminum, 0.125 inch thick 7075 aluminum, and 0.0625 inch thick titanium. Figures 7–9 (see page 22) show the results for the experimental series conducted with a 3,000 feet per second FSP impacting the second panel surface.

The mean of the measured damage holes in Figure 7 range from 1.2–1.6 cm with the thinner 2024 and 7075 aluminum alloys having slightly smaller holes than the thicker 7075 plate and the higher density titanium plate. Post firing examination of the damage holes indicated some material was lost (plugging) as well as flowed at the edges.

The interaction of the fragment with the second panel in terms of the impact flash is presented in Figure 8. The relative intensity data in Figure 8 does not show as great of variability for the studied materials as the primary impact flash measurements in Figure 5.

The larger damage hole for the titanium panel translates to one of the higher observed relative intensities but given the variability within the data for the two aluminum alloys shown and with the average measured intensities within 15 percent for all materials studied, it is difficult to conclude considerable relative intensity differences for the materials examined. Figure 9 gives the flash duration times for each material type.

It appears that the aluminum at the two studied thicknesses have average flash durations on the order of 10 meters per second while titanium is longer at a 60 meters per second average.

The secondary impact flash studies conducted at FSP velocities of approximately 6,000 feet per second utilize the same materials, conditions, and measurements as the 3,000 feet per second studies. Figure 10 (see page 22) presents the damage holes caused by the 6,000 feet per second FSP impacting the second panel.

Comparing the experimental data in Figure 10 with average values of 1.58–1.93 cm versus the data in Figure 7, with 1.2–1.6 cm, the increased fragment velocity yields greater damage hole sizes. Examination of the damage holes indicated some material was lost (plugging) and flowed at the edges, but no pedaling or cracking was observed. For the relative impact flash intensities, which are given in Figure 11 (see page 23), the same material trends are not quite observed.

The average relative flash intensities in Figure 11 indicate that the 0.0625 inch thick 2024 aluminum, 0.0625 inch thick 7075 aluminum, and 0.0625 inch thick titanium have relative intensities greater than one (0.125 inch thick 7075 aluminum) and are higher (19–33 percent) than those observed for the same materials fired at 3,000 feet per second. It should be noted that the relative flash intensity for 0.125 inch thick 7075 aluminum material was seven percent higher when fired at 6,000 feet per second versus 3,000 feet per second. Also the relative intensity material trends hold between the two different FSP velocities for the 0.0625 inch thick panels: 7075 aluminum < 2024 aluminum < titanium. Figure 12 (see page 23) exhibits the impact flash durations for the firings at 6,000 feet per second.

The average flash duration data in Figure 12 follows the same material behavior as the data in Figure 11. Besides the increase in flash duration magnitude relative to the 3,000 feet per second experimental series, the titanium material again has the longest duration of the materials studied.

Discussion and Summary

Historically, the flash seen on the front face of a fuel tank wall was assumed to be either too weak or was quenched by the fuel spray to cause ignition. This is true in some cases, but the data presented here for the primary impact experimental series indicates an energetic phenomenon that might be capable of creating a fire. Further data from the secondary impact flash experimental series has collected intensity data on the first and second panels and showed for the FSP striking the 0.125 inch thick aluminum panels at the two studied velocities that the second plate flash intensity is at least equal to the first plate flash at 3,000 feet per second, while at the higher speed, 6,000 feet per second, the second plate flash intensity showed a longer duration than the front plate flash intensities. The obtained data is being further analyzed for validation of the FPM.

- For the studies that investigated primary impact flash, generally the experimental outcomes appear to relate to the materials' physical and mechanical properties. That is, the nonmetal panels at lower densities, tensile strengths, but higher elongation mechanics suffer lower damage values. However, the metals of higher strength and densities yield more energetic flashes.

- The secondary impact flash experiments conducted with fragment velocities of 3,000 and 6,000 feet per second reveal that the experimental results typically increased in magnitude for damage holes, relative flash intensities and the flash durations but the material responsive trends were maintained between the two velocities. It is difficult to observe statistically significant response differences based on changes for aluminum alloys and material thickness, but variability was observed when comparing aluminum to titanium.

Acknowledgements

Much of the work discussed here was supported via consultation with Andy Pascal (Enthalpy, Inc.).

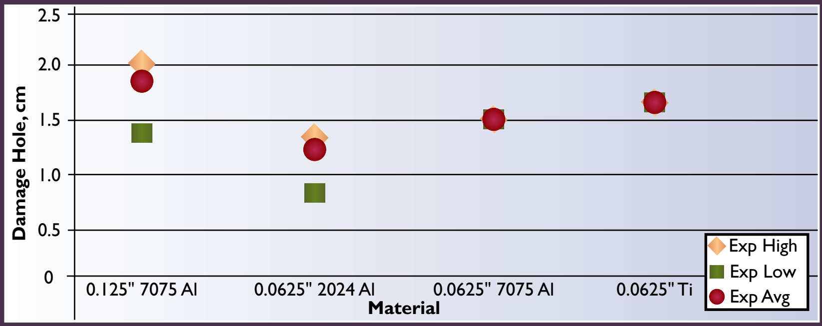

Figure 7. Second panel damage holes for fragment studies of secondary impact flash with average fragment velocities of 3,201 feet per second for 0.125 inch 7075 aluminum, 3,206 feet per second for 0.0625 inch 2024 aluminum, 3,196 feet per second for 0.0625 inch 7075 aluminum, and 3,131 for feet per second 0.0625 inch titanium.

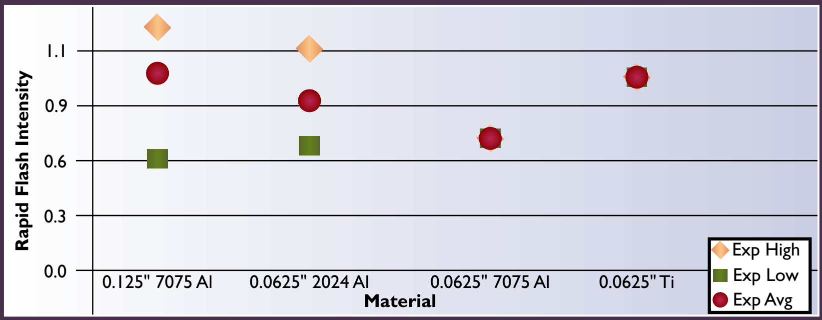

Figure 8. Relative impact flash intensities for fragment studies of secondary impact flash fragment velocities of 3,000 feet per second.

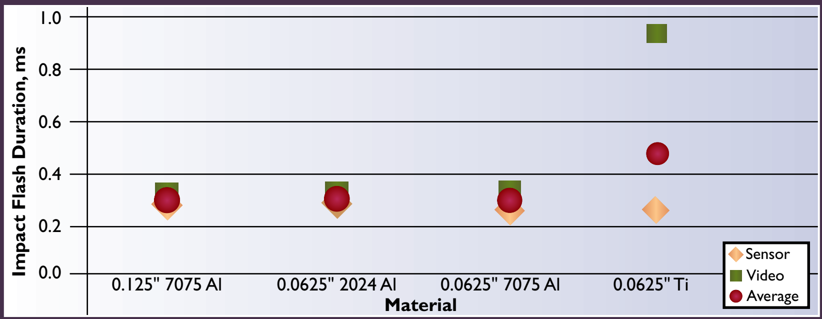

Figure 9. Impact flash durations for fragment studies of secondary impact flash fragment velocities of 3,000 ft/s.

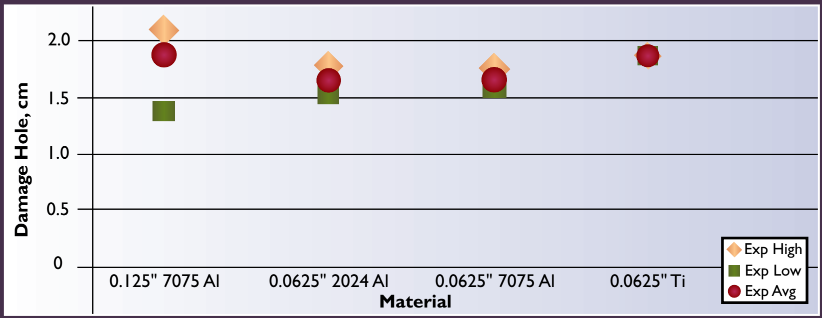

Figure 10. Second panel damage holes for fragment studies of secondary impact flash at average velocities of 5,768 ft/s for 0.125 inch 7075 aluminum, 5,419 ft/s for 0.0625 inch 2024 aluminum, 5,680 ft/s for 0.0625 inch 7075 aluminum, and 5,656 for ft/s 0.0625 inch titanium.

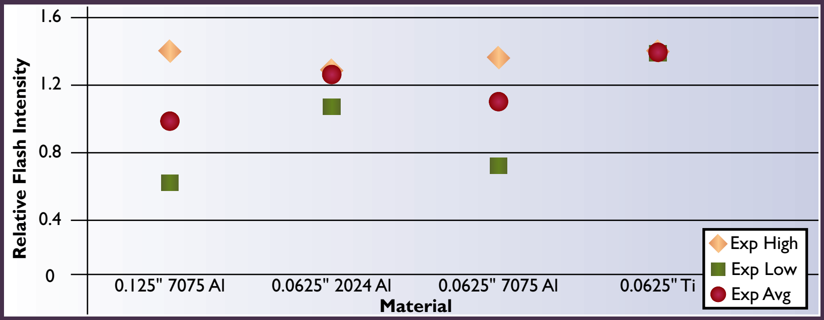

Figure 11. Relative impact flash intensities for fragment studies of secondary impact flash at 6,000 ft/s. It should be noted that the experimental high values appear very consistent.

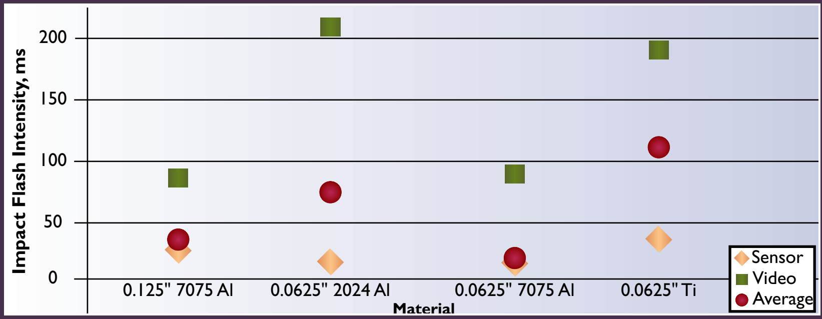

Figure 12. Impact flash durations for fragment studies of secondary impact flash at 6,000 ft/s.

The experiments were technically supported by Dawnn Saunders (Dynamic Sciences, Inc.). The authors would like to express many thanks to Jim Rogers (formerly of the U.S. Army Research Laboratory Welding Shop) for his assistance in the experimental configurations and to William Nori of International Imaging Center for his video expertise. This work was financially supported through the Survivability and Lethality Analysis Directorate of ARL under the Target Interaction Lethality and Vulnerability (TILV) mission program. ■

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1. J. Baird, Hough, G., and King, T., Int. J. Impact Engng, Vol. 19, No 3., 273-276, (1997) .

Editor's Note: The Fire Protection Model is being developed by Andy Pascal of Enthalpy Corporation with support from the JASPO, ARL, and several Air Force Program offices. This article reports on an ARL project to provide experimental data to help validate the Fire Prediction Model. Enhancements and validation efforts are continuing.

For information about the ARL testing, please contact Dr. R. Reed Skaggs at AMSRL-WM-TB, APG, MD, 21005, Phone: 410.278.9329, Fax: 410.278.8736, E-mail: rskaggs@arl.army.mil.

For information about the model please contact the Model Manager—Marty Lentz, 46 OG/OGM/OL–AC, 2700 D Street, Building 1661, Wright-Patterson AFB, Ohio 45433–7605, Phone: 937.255.6302, ext. 241, Fax: 937.255.2237, E-mail: martin.lentz@wpafb.af.mil

Dr. R. Reed Skaggs received his Ph.D. in Physical Chemistry from George Washington University in 1997. From 1997 to 1999, he worked as an ASEE Postdoctoral Fellow at the U.S. Army Research Laboratory. He is a research chemist for ARL's Terminal Effects Division since April 1999. He is also a Work Package Manager for Crew, Component, and Structure Survivability for Ground Combat Vehicles which includes fire protection, ballistic shock, and land-mine effects. He may be reached at rskaggs@arl.army.mil

Ms. A. Canami is from the Army Research Laboratory at Aberdeen Proving Ground in Maryland.

RamGun Provides New Path to Survivable Wingbox Design

■ by Mr. Gregory J. Czarnecki, Dr. Monty A. Moshier, and Dr. Ronald L. Hinrichsen

Under direction of the Joint Aircraft Survivability Program Office (JASPO), a test device has been designed and proven capable of realistically and economically assessing skin-spar joint resistance to hydrodynamic ram pressures. Known as a RamGun, this device was developed through a partnership between the Air Force 46th Test Wing and RHAMM Technologies.

Evaluation of aircraft vulnerability to a given threat commonly includes an assessment of the structure's response to hydrodynamic ram pressures. Hydrodynamic ram is produced when high velocity or exploding projectiles interact with fluid-filled regions, as in wing fuel tanks. The result is a brief pressure pulse in the fluid that can exceed 10,000 pounds per square inch (psi). This event is potentially catastrophic for aircraft fuel tanks designed to survive sustained pressures of little more than 50 psi. Significant ram events can rupture fuel-cell walls and produce structural damage that extends over several bays. While the magnitude of ram pressure is dictated by a combination of fuel-level and projectile threat, skin-spar joint design is the primary means by which damage can otherwise be controlled. Damage resistant joints restrict the spread of damage and assist aircraft survival.

Conventionally, joint resistance to ram is evaluated using a combination of two methods—T-section pulloff tests and ballistically-tested wingboxes. While T-section tests are a low-cost method of ranking skin-spar joints according to their load to failure, realism is traded away in favor of an economical and easily understood test. Where T-section pulloff tests are symmetrically performed at a rate of less than 0.01 in/sec, projectile-generated ram events involve asymmetric high-rate loading conditions on the order of 100 in/sec. Although wingbox ram tests with actual threat projectiles are realistic, tests of this sort come with a price tag in excess of $250,000—too expensive for wholesale evaluation of competing joint concepts.

Concept definition

In an attempt to devise an economical and realistic test process for assessing joint resistance to ram, the 46th Test Wing's Aerospace Survivability and Safety Flight adopted a model-test-model approach. The project's goal was to design and demonstrate a test method capable of generating and delivering a ram-like pressure pulse to a joint test-specimen. Test fixture design had to allow single and double-spar joint tests. Single-spar tests allow direct correlation with results from conventional T-section pulloffs. Double-spar tests provide the greatest degree of realism by including asymmetric loading effects. To mimic projectile-generated ram conditions, the pressure pulse had to have requisite peak and impulse characteristics. The joint's boundary conditions (constraints) also needed to be representative of wing structure. To achieve these goals, the 46TW relied on the modeling services of RHAMM Technologies. RHAMM expanded upon an undeveloped "RamGun" theme initiated by the U.S. Air Force Research Laboratory several years ago. The original RamGun system consisted of a large-diameter gas gun designed to launch a cylindrical steel projectile into a piston. The piston was there to transmit the impact energy into a fluid column, forming a ram pressure wave. Earlier in the project, RHAMM discovered several inadequacies (pointed out through modeling and later verified through testing) in the original RamGun design. The fluid column had to be redesigned with a reduced-thickness impact face, eliminating the piston. Doing so was required to form a single ram wave of correct amplitude and length. In addition, the fluid column's housing was decoupled front-to-rear to prevent an occurrence of a spurious stress wave in the housing. Without decoupling, an impact-generated stress wave in the housing interferes

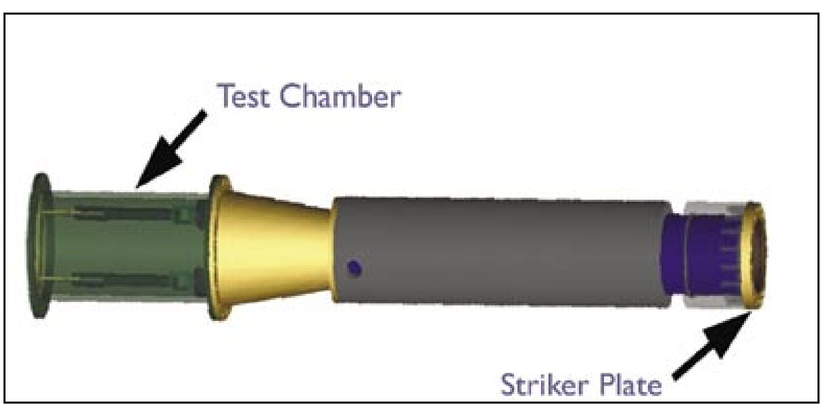

Figure 1. RamGun

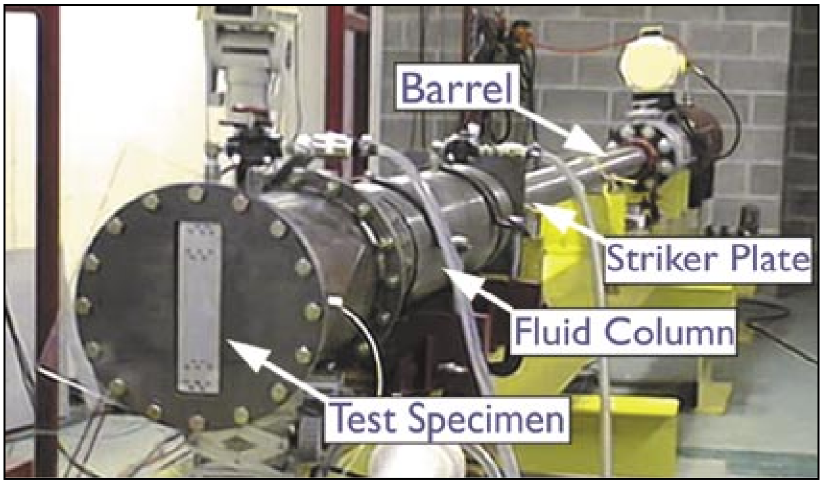

Figure 2. RamGun fluid column

with the fluid column's ram wave. Furthermore, test chamber design required an expansion of the fluid column diameter to accept appropriately-sized joint test specimens. Test chamber design also required an ability to correctly constrain both single and double-spar joints without upsetting the pressure pulse. Finally, provisions for pressure sensors, load cells, and strain gages needed to be integrated in the design.

Experimental results

Early tests with the upgraded RamGun demonstrated the value of pre-test modeling. LSDyna3D predictions and RamGun performance were right on the mark. Several successful tests were conducted for demonstration purposes. One of the first articles tested was a bolted aluminum two-spar specimen. The ram pulse generated severe plastic deformation as the skin attempted to pull off of the spar legs. In a follow-on test, a bonded aluminum two-spar joint did not fare so well. Skin was ripped from the spar caps as transient pressures in the fluid column approached 10,000 psi. Other demonstrations of RamGun performance included single-spar joints of both aluminum and composite construction. In each case, ram loads proved sufficient to fail the joints with a corresponding revelation of each joint's high-strain rate load-to-failure.

The RamGun design success now opens the door to a wide array of skin-spar joint tests supporting the design of future air vehicles. By incorporating improved damage-resistant joints in aircraft design, warfighters are provided with an added layer of protection.

Summary

Development of the 46th Test Wing's RamGun has proven the benefits of merging modeling and testing. Modeling provided direction and insight as the RamGun was brought forward from conceptual stages to a working beneficial test system. The RamGun now provides a one of a kind capability for testing single and double T-joint specimens under realistic boundary conditions and strain rates. Lockheed Martin now plans to use the RamGun to assess ram-resistance of advanced joints for improved aircraft survivability. ■

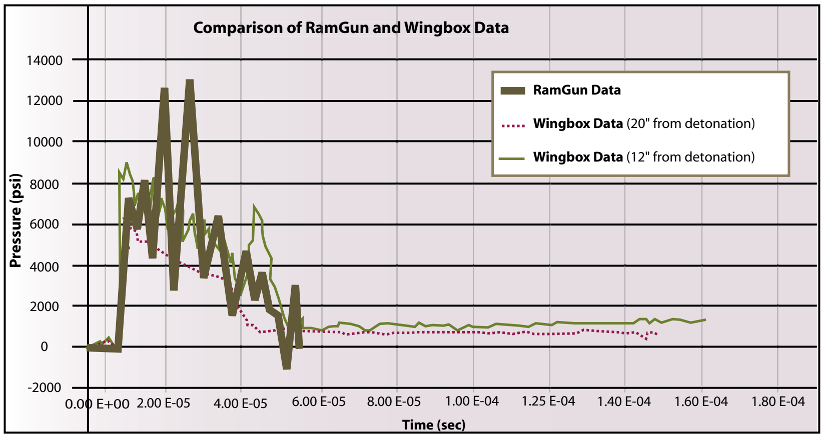

Figure 3. Comparison of RamGun and Wingbox Data

Mr. Greg Czarnecki received his BS in Civil Engineering and his MS in Materials Engineering from the University of Dayton. He is a civilian with the 46th Test Wing's Aerospace Survivability and Safety Flight. Mr. Czarnecki is the chairman of the Structures Committee under the JASPO Vulnerability Reduction Subgroup. He may be reached at gregory.czarnecki@wpafb.af.mil.

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Dr. J. Michael (Mike) Bennett

Young Engineers in Survivability

■ By Mr. Dale B. Atkinson

The Joint Aircraft Survivability Program Office (JASPO) is pleased to recognize Dr. J. Michael (Mike) Bennett as our next Young Engineer in Survivability. Dr. Bennett is nationally and internationally recognized as one of the leading engineers in the fire protection area in both government and industry.

Dr. Bennett graduated from the University of Louisville with a B.S. and M.S. in Mechanical Engineering in 1986 and 1987, respectively. While at the University of Louisville, Mike got his first taste of survivability testing and system design by abusing refrigerators in a test facility designed to simulate the rigors of shipping and delivery, as a co-op student serving at General Electric Appliance Park. He also designed several refrigerator components that were later patented.

After graduation, Mike accepted a position with the Safety and Survivability Branch of the Air Force Research Laboratory at Wright-Patterson Air Force Base in Dayton, Ohio, which was recently re-designated the Aerospace Safety and Survivability Flight of the 46th Test Wing. In one of his initial assignments, Mike was the project engineer for the F–15 Crew Station Vulnerability Program, which evaluated the safety and survivability of pilots to multiple injury mechanisms in combat, such as burns, toxic fumes, blast pressures, and penetrating injuries. To accurately collect test data of projectile injury to the pilot, Mike devised the Aerospace Incapacitation Response Manikin (AIRMAN), employing materials previously used to capture meteorites in space, to accurately preserve the trajectory and speed of impacting fragments to and provide quality input to injury models. Then, Mike established the Advanced Rapid Response Explosion Suppression Technologies (ARREST) Program to investigate new technologies, such as machine vision fire detectors, supersonic water fog fuel tank explosion suppression systems, and solid propellant gas generator fire extinguishers for aircraft fire and explosion applications. The new gas generator fire extinguishers have been very successful and have been applied to several new aircraft by the Navy.

In 1994, Mike created and served as Technical Director of the National Halon Replacement Program for Aviation, a $23 million, multi-year effort to find a military and commercial aviation replacement for halon that would satisfy the International Montreal Protocol Treaty and U.S. Clean Air Act requirements. While incorporating the requirements of a myriad of aircraft, an acceptable extinguishing chemical was identified and demonstrated, and a design methodology developed, that was subsequently employed on the Navy V–22 and F/A–18 E/F aircraft, and the U.S. Air Force F/A–22. For this accomplishment Mike and his multi-service team received the EPA Stratospheric Ozone Protection Award and the U.S. Air Force Material Command Science and Technology Award. Mike then assisted in creating and later serving as the U.S. Air Force representative on the Technical Coordinating Committee of the Department of Defense (DoD) Next Generation Fire Suppression Technology Program (NGP), a ten year program to develop improved fire extinguishing products for military aircraft, ships, and armored vehicles. Mike also served in various capacities in the field of aviation and fire protection such as chairman of the FAA Fire Protection Engine Certification Committee, as the Research Committee Chair of the International Conference on Halon Replacement in Aviation, and was also a U.S. Air Force nominee for the GEICO Public Service Award in fire safety. His fire protection development activities have been profiled on the television programs "CNN Future Watch," "Scientific American Frontiers," and "The NBC Nightly News." He has been featured in publications such as *Aviation Week*, *Scientific American*, *The Wall Street Journal*, *Circle Track* magazine, and the *Aircraft Survivability* magazine.

In 1997, Mike began activities in pursuit of a doctorate in Mechanical Engineering and received his Ph.D. (specializing in combustion) from the University of Dayton in May 2003. His dissertation focused on the mechanisms of fluid stream ignition on hot surfaces with the results and subsequent predictive model having direct applicability to the problems of hot surface ignition experienced in aircraft engine nacelles.

Mike has been a long time participant in the JASPO (formerly the JTCG/AS), and served as co-chairman of the Fuel Systems Committee for a number of years. He has greatly contributed to the work of the JASPO, which has been a leader in aircraft fire and explosion suppression technology development. He conducted and oversaw fire protection programs at the U.S. Air Force's Aircraft Survivability Research Facility and Aircraft Engine

Nacelle Test Facility for all three U.S. military Services, as well as international customers, including joint fire protection system design activities with Russian, Swedish, and British collaborators. One of his recent innovations under the JASPO is the Instant Fire Walls concept, employing intumescent coatings in strategically placed structures to provide fire containment and suppression in ventilated spaces such as aircraft engine nacelle. (Note: See related article in this issue on page 40.)

In his younger days, Mike built and raced three stock cars. As a result, he has always had a strong interest in fire protection for race cars. In addition to his military-focused work in aircraft fire protection, he has been provided opportunities to assist in the design of fire protection for cars and developed a number of innovative fire protection systems for race cars and other vehicles, several of which have been patented and deployed. Mike also provided consultation on the design of a fire protection system for Funny Car dragsters which involved testing an actual dragster under 225 mph airflow conditions in the Aircraft Survivability Research Facility to evaluate a new onboard fire suppression system under realistic fire incident conditions seen on the race track. Mike has served as a consultant to General Motors, John Deere, and others. He is now serving as a board member of the National Safety and Transportation Institute where he has been commissioned to prepare and instruct a series of professional training classes at Villanova University pertaining to vehicle fire safety and investigation. Mike has left the government and is now chief manager of Bennettech, LLC, a company dedicated to fire safety technology development and consultation, located in Nashville, Tennessee. His wife, Ginger Bennett, who is an expert in fire protection in her own right, serves in this capacity as an Associate with Booz Allen Hamilton. His current activities include assistance to the U.S. Army and Air Force in the testing and design of environmentally-acceptable fire extinguishing solutions for the engine nacelles of the RAH–66 Comanche helicopter (and several additional rotorcraft platforms), devising the testing protocol for new fire technologies produced by the NGP, and several commercial pursuits.

It is with great pleasure that the JASPO presents Dr. J. Michael (Mike) Bennett as our latest Young Engineer in Survivability. ■

Mr. Dale Atkinson is a consultant on the aircraft combat survivability area. He retired from the Office of Secretary of Defense in 1992 after 34 years of government service and remains active in the survivability community. Mr. Atkinson played a major role in establishing survivability as a design discipline and was a charter member of the tri-Service JASPO. He was also one of the founders of the DoD-sponsored SURVIAC. He may be reached at jasnewsletter@jcs.mil.

Airborne Fireball. Dr. Bennett discovered the phenomena of "airborne" ignition resulting from hot surface contact, and was able to mathematically predict these events.

Firefox Car. The Firefox fire protection system for dragsters could be tested realistically "at speed" at the Air Force survivability test facilities, which was certified on site by the National Hot Rod Association.

The Future of Combat Aircraft Survivability

Multifunction Electro-optics for Defense of U.S. Aircraft (MEDUSA)

■ by Mr. John F. Carr, Lt Col Gregory J. Vansuch, Dr. Duane A. Warner, and Mr. William R. Taylor

The rapid proliferation of passive electro-optical (EO) and infrared (IR) threats throughout the world puts U.S. aircraft at risk. As the threat evolves it becomes necessary to develop new countermeasure approaches. One approach is to move from reactive endgame countermeasures, such as decoys and jammers, to a capability to proactively deny launch and put threat EO/IR systems at risk.

The Defense Advanced Research Projects Agency (DARPA)-led, Air Force Research Laboratory (AFRL)-managed, Multifunction Electro-optics for Defense of U.S. Aircraft (MEDUSA) program is taking this approach, and is a future generation laser-based system to be used for aircraft self protection. It will be the first multi-spectral system to accomplish both self protection and offensive functions from a single set of electro-optical sensors. This revolutionary program takes its name from the ancient Greek Gorgon of mythology who turned into stone all those who looked upon her face and serpentine locks.

The goal of the MEDUSA program is to develop and demonstrate an advanced EO/IR countermeasure (CM) capability that will proactively detect, disable and destroy all ground-based and airborne EO/IR threats from any tactical aircraft. This highly complex program leverages the technical expertise of numerous government and contractor engineers and scientists to assure its success.

The MEDUSA program is comprised of three distinct yet interrelated efforts: Component Technology Development, System Development, and Measurements and Techniques.

The Component Technology Development effort involves the advancement of laser, detector, beam steering and energy transfer technologies that will be required to accomplish MEDUSA performance.

The System Development effort includes the design, development, fabrication, assembly, test, and demonstration of the MEDUSA system.

Measurements and techniques activities involve research in the areas of optical signatures, optical exploitation, active clutter measurements, CM techniques and effects, and modeling and simulation (M&S).

Proliferation of EO/IR Threats

U.S. advances in radio frequency (RF) electronic warfare have forced our adversaries to incorporate EO/IR sensors into their air defense weapon systems. The EO/IR threat exists in two distinct modes of operation: as a part of the fire control system and in antiaircraft missile seekers. For the fire control systems these sensors might be forward-looking infrared (FLIR) as seen in Figure 1, infrared search and track (IRST) as seen in Figure 2 (see page 29), low light level television, night vision devices or charge coupled device sensors.

In some cases the fire control systems are exclusively electro-optical (an example being a laser beamrider missile) as seen in Figure 3 (see page 30), and in some cases the sensors provide an adjunct capability to threats that primarily use RF sensors as seen in Figure 4 (see page 31). For the missile seekers, reticle scanners are the norm with staring IR arrays very evident in the new antiaircraft missile.

The profusion of EO/IR threats is staggering. There are few "RF-only" threats remaining in the world and development in that area has slowed. Tracking and fire control can be accomplished with radar or EO/IR sensors. When the RF threat is jammed, the EO/IR redundancy ensures continued operation of the threat. Furthermore, EO/IR trackers

Figure 1. Mistral with FLIR sight

Figure 2. Fulcrum infrared search and track (IRST)

allow "RF silent launch" modes. Consequently, there is no emission, and no warning, until end-game. Over 90 percent of the short-range surface to air missile (SAM) systems have an EO/IR capability. All anti-aircraft artillery (AAA) can be easily retrofitted with night vision capability. The proliferation of these passive EO/IR threats throughout the world puts U.S. aircraft at risk.

MEDUSA Response

Aircraft self-protection will be the primary design focus for MEDUSA. Simply put, all ground-based and airborne EO/IR threats will be negated. MEDUSA will sense that it is being observed and determine the best method of dealing with the observer. As the design of this capability is developed, other multifunction capabilities, such as target designation, identification, navigation, or reconnaissance may be added.

MEDUSA's aircraft self-protection capability will incorporate new layers of defense beyond the legacy functions of missile warning and missile CM. Implementation of this layered defense suggests that MEDUSA will need, at a minimum, the following functional capabilities: search, track, ID, missile warning and countermeasures. The primary objective of the search function is to proactively look for electro-optical systems tracking the aircraft. These passive tracking systems include optics associated with fire control systems as well as guidance optics in missiles that have not yet been launched. The track function will locate the optics accurately relative to the aircraft during the threat/aircraft encounter for a successful application of the countermeasure. The ID function will determine the characteristics of the observer with sufficient detail so that the appropriate CM can be successfully implemented and allow targeting of the threat.

These new functions allow three layers of defense. The first layer is to avoid the threat by detecting it prior to intruding into the missile launch envelope. MEDUSA will detect EO/IR threats by scanning the field of regard with a search laser. By finding these threats early, a pilot can choose to change routes and avoid the threat completely.

The second layer of defense is to defeat the enemy acquisition and track sensors prior to launch.

The third layer of defense is to defeat the EO/IR guidance sensor following launch. In this situation the threat system is either providing guidance information to a launched weapon (e.g., beam rider) or is a sensor on the weapon.

These three layers of defense will not interfere with the existing capability to deploy decoys and expendables, which forms the fourth layer of aircraft defense. In addition to these defensive functions, MEDUSA also emphasizes multifunction, secondary capabilities that might be available with active/passive EO systems. Examples include situational awareness, collection of intelligence data, weapons delivery, target designation and battle damage assessment.

Program Structure Component Development

Thirteen component technology development efforts are underway to respond to technical objectives in the areas of high gain detectors, multifunction lasers, countermeasure lasers, infrared fibers, and non-gimbaled beam steering. All of these technologies are essential for MEDUSA to meet performance objectives. The need to achieve system performance at greater ranges and in smaller packages continues to drive the development requirements of these technologies. Performance objectives also will drive the MEDUSA system development. Estimates of required technical performance follow.

Staring Array Detectors

The MEDUSA concept envisions an infrared imaging capability to support missile warning and aircrew control/situational awareness functions. This requires focal plane array detectors with large numbers of pixels for high resolution and wide field-of-view (FOV), as well as spectral discrimination in the near, mid and long wave infrared bands. High frame rates and on-chip processing are also needed to address the multivariant threats.

Advanced Receivers: to support the need for better LADAR threat detection range, a MEDUSA system will need more sensitive infrared receivers. Both IR avalanche photodiodes (APD) and optical power amplifiers are being developed, and will be needed in large arrays for both mid-IR and far-IR.

Multifunction Laser

Multifunction laser refers to a laser, or system of lasers, that will be used for a variety of functions, including threat search, threat classification and identification, and jamming. Most, if not all, of these functions will have to be done in multiple wavelength bands from near to far IR. In order to fill all of these roles, the pulse repetition frequency must be controllable. The laser must be tunable, and wide band. The search function will require multi-Watt average power, with low beam divergence and high beam quality. The coherence length of the beam may have to be long enough to enable a coherent laser radar capability. While there are mature laser technologies that address many of these requirements, designing a laser source architecture to address them all in a small, flight-worthy, affordable package is the technical challenge.

Countermeasure Laser

Some EO/IR threats are highly resistant to jamming techniques and expendables. The MEDUSA system must be capable of depositing enough energy on these detectors to disable, damage or destroy them. If lasers can be developed at wavelengths in each sensor band, the optical gain of the system means that this can be done with reasonable pulse energies.

Beam Steering: MEDUSA will need a capability to direct and control laser beams used for LADAR and CM without affecting the airflow or observables of the aircraft. A very small, very broad band, conformal aperture capable of accommodating steering through wide angles without significant degradation in beam quality or power is required. Many areas of active work, including liquid crystal beam steering, micro mirrors and lenses or miniaturized gimbals show potential to meet these requirements.

Infrared Fibers/Waveguides

MEDUSA will likely require that laser energy be distributed from a central location to multiple apertures. IR fibers or waveguides will be needed with the following characteristics: low loss/attenuation, high damage threshold, multi-spectral bandwidth, flexibility and multimode/single mode capability to preserve high beam quality.

System Development

Three independent System Development Efforts are underway to design, develop, fabricate, assemble and demonstrate an affordable, multi-functional, multi-spectral electro-optical MEDUSA system. The system goals to be demonstrated by the MEDUSA program are to provide aircraft self-protection against all classes of EO/IR ground-based and airborne threats; be scalable for installation in relevant current and future fighter aircraft; and support the accomplishment of other capabilities such as situational awareness, collection of intelligence data or weapons delivery.

These System Development contractors are using validated systems engineering processes such as Integrated Product and Process Development (IPPD) in the design, development, fabrication, assembly and demonstration of MEDUSA. The System Developers will use IPPD to integrate MEDUSA requirements in five major categories (basic performance, mission suitability, multifunctional performance, cost and maturity) with realistic mission scenarios to evaluate each MEDUSA design. Overall design performance relative to MEDUSA requirements and realistic mission profiles will be quantified and presented with risk estimates for meeting minimum thresholds.

The demonstrated MEDUSA system technologies do not have to achieve the final small package size, but a clear and reasonable path to achieve the small size must be highly evident and compatible for implementation into future MEDUSA flight demonstrations.

Measurement /Technique Research Sensor Characterization

Optical Signatures

Optical signatures are a key driver of the laser radar subsystem performance requirements for the search and classification functions. There are well-established techniques for this type of measurement, and MEDUSA government and in-house contractor personnel have considerable experience in this field. Although many

Figure 3. RBS–70 laser beam rider with clip-on night device (COND)

foreign systems have been exploited in the past, the measurements made on these systems often don't have the resolution needed for determining MEDUSA performance requirements. To support analysis of innovative search schemes, AFRL/SNJW and AFRL/DELS will standardize the established techniques to characterize how optical signatures depend on a wide variety of parameters.

The Laser IRCM Development (LID) range at Wright-Patterson AFB will be used to make measurements at realistic ranges. At the same time, the LID range also will be used to make measurements that support the classify/ID function and CM techniques function. These measurements are non-destructive and will be performed on all threats and on surrogates.

With this data, it will be possible to identify the nature of the optical signatures and perform theory-based modeling to investigate effects of receiver geometry.

In addition to the above tests that will be performed on every threat and surrogate available, AFRL/DELS also has the capability and facilities to perform field tests to verify maximum detection range (at boresight and edges of FOV) and irradiance at target plane. These field tests may not be done on every sensor due to time/cost, but will be performed selectively to validate the lab test results.

Sensor Performance Measurements

The Optical Exploitation facility at Wright-Patterson AFB, Ohio, is conducting sensor performance measurements of a wide variety of E-O threat sensors in a laboratory environment. Threat sensor technologies are being characterized and their susceptibilities exploited to support MEDUSA system developers.

Active Clutter Measurements
It will be impossible to model the search function based on knowledge of the target alone – it is essential that the clutter environment be considered as well. Clutter here refers to the background and natural or man-made discrete objects that a MEDUSA system must distinguish from true threat systems. While some data exists, most of it is in visible/NIR wavelengths. The vast majority of it is from a static sensor, which a) cannot capture the key temporal nature of the clutter and b) can only sample a very small area. An existing clutter model has been validated in the visible/NIR spectral region. In order to extend this model into the MWIR/LWIR, AFRL will experimentally measure some parameters of the model.

Ideally one would like to measure the bi-directional reflectance distribution function (BRDF). In principle, it should be possible to measure BRDF in the lab, but it is difficult to adequately simulate a natural scene in the lab. As a result, AFRL is acquiring the necessary data three different ways—static tower measurements, vehicle-based data collection, and airborne data collection. The static tower collection is the least expensive, but only offers a very limited amount of data. The mobile system is somewhat more expensive, but offers the ability to measure different terrain types and to measure the same ground spots from different look angles in order to characterize the extent of any glints. The airborne collection system is significantly more expensive, but offers the data that most directly correlates to the needs and reduces the amount of time required per km2 of ground to be measured.

CM Techniques and Effects
Once a threat has been detected and classified as a threat, the warfighter will need some means of negating it through expendables, jamming, damage, or a combination of those techniques. Countermeasure techniques that can be used preemptively (before launch) and destructively are preferred, but the top priority is to protect the aircraft and crew. There has been significant work in the past with hardware-in-the-loop (HITL) testing and simulations in the areas of closed-loop IRCM (CLIRCM) jamming (although most data is for reticle-based missile seekers) and in damage effects against staring sensors. More information is required before System Developers can design a realistic system.

This effort will be conducted cooperatively with AFRL/SNJW and AFRL/DELS in order to take full advantage of existing facilities and expertise. The division of labor is best split along the lines of countermeasure type.

Jamming (AFRL/SNJW)
Jamming in this sense is a general term to include all non-destructive laser-based CM. Jamming in the classical sense attacks the tracking algorithms.

The main method to assess these techniques is field testing on the LID range. AFRL will use surrogate tracking sensors to establish a library of possible jamming techniques to be attempted against actual threat systems. The sensor under test tracks an artificial heat source (usually a hot plate or propane burner) that is placed a short distance away from the laser to simulate the separation between the engine and the laser on an actual aircraft.

After the effect of different jam codes on the system has been measured on the LID range, AFRL will incorporate those effects into the digital model. This is necessary in order to ensure that AFRL understands how the jamming will affect the tracker given the correct relative motion of the target, which cannot be simulated in the tower tests.

Damage Mechanisms and Effects (AFRL/DELE)
This effort will continue to study the damage mechanisms of detector arrays, which drives the requirements for damage lasers and pointing accuracy and stability. The fundamental processes of damage will be inves-

Figure 4. EO/IR adjunct of existing SA–8 RF missile

tigated and coupled to theoretical models in order to understand how damage threshold depends on different laser parameters. Most of this effort does not require actual threat systems because the items under test will be the detector arrays rather than complete sensors.

Damage CM technique assessment will study the effectiveness of varying levels and types of sensor damage in degrading threat performance. This will be accomplished primarily through modeling and simulation to avoid unnecessary destructive tests of real threat sensors.

Combined Effects

It is possible that there will be some sensors that the warfighter cannot counter with any single method. Some preliminary investigations (HITL lab simulations and digital models) suggest that combined countermeasures may be more effective. As an example, one combination would be to use a damage laser to induce local area damage at the same time that a flare is ejected. AFRL will probably not be able to conduct this type of test on every sensor because a) it usually involves destructive testing and b) these CMs are very difficult to create with a simple setup.

Modeling and Simulation (M&S)

An integral part of the MEDUSA in-house effort is modeling and simulation. AFRL/SNJW maintains the resources both in government assets and in contractor support for a fully dedicated working group to perform all the necessary M&S tasks. During the past year, the MEDUSA M&S team assembled a number of disparate models into a collaborative package, and forged ahead with a new philosophy of developing models via graphical programming.

In the early stages of the program, focus was placed on scenario development. Using such models as Modeling System for Advanced Investigation of Countermeasures (MOSAIC) for a multitude of Infrared (IR) Surface-to-Air Missiles (SAMs), Enhanced Surface-To-Air Missile Simulation (ESAMS) for SAMs with Electronic Countermeasures (ECM) capability, and RADGUNS for Anti-Aircraft Artillery (AAA) threat, scenarios were generated and tested. Continuing work behind the scenes included incorporating Improved Stratospheric and Mesospheric Sounder (ISAMS) for image seeker representation into MOSAIC, obtaining a laser beam rider model, and the development of a clutter model from Georgia Tech Research Institute (GTRI). Focus is now shifting to support the systems engineering evaluation criteria. M&S will serve its purpose here as a tool for program management to use in the down select process. M&S will also provide functional decompositions of the search subsystem, imaging tracker/seeker object, combined countermeasure effects, and classification and identification of threats. Further phases will incorporate combined CM effects within the integrated system simulation, develop a test plan for validation and verification, develop user interfaces and post processing tools, and ultimately develop a complete end-to-end model of the MEDUSA system.

Conclusion

MEDUSA is a dramatic leap forward in protecting aircraft against EO/IR air defenses as well as providing functional capabilities not normally expected from a self protection system. It takes the U.S. from the current mode of reactionary endgame countermeasures to proactive, early, and multi-layered countermeasures. It will not only increase aircraft survivability, but also increase the effectiveness of U.S. air power, and allows us to keep control of tempo and nature of the air war. ■

Authors' Note

The authors acknowledge the contributions made to this paper by Dr. George Vogel, Mr. Donald M. "Sandy" Smith, Maj Michael Hawks, Mr. Jan Servaites, Mr. Mike Pershing, Mr. Luke Borntrager, Mr. Adam Coleman, Mr. Stan Herr, Mr. Cal Verity, and Mr. Michael Wager.

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Dr. Duane Warner joined AFRL in 1980 to specifically work on the advanced development of electro-optical countermeasures systems. His previous AFRL efforts included Compass Hammer, Coronet Prince and LIFE programs. He joined the MEDUSA team in 2001. His prior AF experience was as a systems engineer working the B–1A offensive and defensive avionics systems, and he was also the chief avionics engineer during the engineering development of the Ground Launched Cruise Missile. He has a BS in Eng. Physics and a M.S. in Physics from The Ohio State University and a PhD in Physics from the University of Michigan. He may be reached at duane.warner@wpafb.af.mil.

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Aircraft Survivability 2003

November 3–6, 2003
Naval Postgraduate School, Monterey, California

Sponsors:

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Director, Operational Test and Evaluation
Army Aviation Association of America
American Institute of Aeronautics and Astronautics
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Marine Corps Aviation Association

Symposium Theme and Goals:

The theme of this year's SECRET/NOFORN symposium is "Reclaiming the Low Altitude Battlespace." Combat flight operations at low altitude pose special survivability challenges for aircraft, both manned and unmanned. While many combat missions may be executed from outside AAA and MANPADS threat envelopes, rotorcraft, fixed-wing air lifters, and tactical unmanned vehicles, by the very nature of their missions, must operate in the hazardous low altitude flight regime. Tactical fighters may have to operate there as well. The symposium has two principal goals. The first is to acquaint the manned and unmanned aircraft communities with the special challenges of low altitude operations. The second goal is to increase awareness of survivability techniques and technologies.

Symposium Overview:

Senior speakers will discuss the role of low altitude operations for both manned and unmanned aircraft in modern warfare. Experts from government and industry will cover various aspects of aircraft survivability technology. A special session on recent combat operations will be presented. The symposium format features long breaks and lunch periods, a welcoming reception, and an evening at the Monterey Bay Aquarium to facilitate networking among attendees.

The symposium will begin on Monday, November 3rd, with a day of tutorial sessions offered by experts in fields of interest to the survivability community. The symposium proper will commence on Tuesday, November 4th, and continue until mid-day on Thursday, November 6th.

Symposium Sessions Summary:

Monday, November 3, 2003, 0800–1700
Tutorial Sessions, Registration and Informal Social

Tuesday, November 4, 2003, 0830–1700
Symposium Introduction, Government and Industry Keynote Addresses
Special Operations Forces—Low Altitude Operators
Survivability Technology Trends
Vulnerability Reduction, Fire Protection & Live Fire Testing

Wednesday, November 5, 2003, 0830–1700
Low Altitude Systems Developments
Stealth, C4I & Countermeasures

Special Wednesday Evening Event at the Monterey Bay Aquarium

Thursday, November 6, 2003, 0830–1200
Low Altitude Survivability Panel
Combat Operations Report

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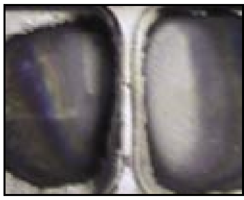
AIAA Survivability Award

Call for Nominations

The American Institute of Aeronautics and Astronautics (AIAA) is accepting nominations for the prestigious Survivability Award. Established in 1993, this award is presented to an individual or a team to recognize outstanding achievement or contribution in design, analysis, implementation and/or education of survivability in an aerospace system. The biennial award will be presented in April 2004 at the Structures, Structural Dynamics and Materials Conference in Palm Springs, California. Nominations must be submitted by October 1, 2003. Past recipients of the award have included Mr. Dale Atkinson, Dr. Robert Ball, Mr. Nikolaos Caravasos, Mr. Jerry Wallick and Mr. Michael Meyers. Forms can be obtained by accessing the following web site: http://www.aiaa.org/, or contacting Aimée Petrognani, AIAA Honors and Awards Liaison, at 703/264–7623 or via E-mail at aimeep@aiaa.org. or Dennis Williams of the AIAA Survivability Technical Committee at 314/232–7955.



Weapons Bay Protection Proof of Concept

■ by Mr. Alex G. Kurtz and Mr. Martin Krammer

The next generation of aircraft will have, or will consider, extensive use of internal carriage of ordnance. Modern "stealthy" aircraft require internally stowed munitions and payloads to reduce their radar signatures. Under varying conditions, internally stowed ordnance can be ballistically initiated by bullets, missile warhead fragments, or anti-aircraft artillery (AAA) projectiles causing the ordinance to potential burn, explode, and/or detonate—hence introducing a hazard to combat aircraft. When ballistically impacted, munitions may exhibit reactions from "no reaction" to "detonation." These reactions can also be transferred to adjacent munitions, which can exhibit the same type of reaction. These phenomena and the severity of these reactions, on a first order basis, have been quantified, with the majority of the reactions as "deflagration" or severe burn. New generation of weapons are less sensitive to bullet/fragment impacts; however, any reaction other than "no reaction," has a very high potential to destroy the aircraft. To reduce aircraft vulnerability, it is necessary to develop a means to detect and protect combat aircraft from these events.

A typical munition ejection sequence can take 4–8 seconds after pilot activation. A burning rocket motor can devastate an unprotected aircraft structure within 1–3 seconds. Joint Live Fire (JLF) and Joint Aircraft Survivability Program Office (JASPO) programs have proven that a thin amount of ablative material can provide critical time needed by the pilot to react to fire warnings, reconfigure the aircraft, cycle the munition ejection sequence, and potentially survive this event.

Under the auspices of the former JTCG/AS, now Joint Aircraft Survivability Program Office (JASPO), a number of high performance ablative/intumescent materials were evaluated with regards to weapons bay applicability. The weapons bay was divided into three zones—

1. Directly behind the rocket motor

2. Adjacent to the rocket motor

3 In front of the rocket motor

Based on a number of laboratory scale tests, full-scale test materials were chosen primarily as a function of protection weight, protection thickness, laboratory scale flame impingement tests (with and without entrained particles), and potential zone protection. The following materials (trade names) were evaluated: MXBE–360, Haveg 41N, Flexfram 605, Pitchar, Firex 2390, Firex 2555, Chartek IV, Havaflex TA–117, KMass, Autostic, Ceraset, FASTBLOCK 800, and C-Foam. Materials were applied to composite or aluminum substrates in thicknesses ranging from 0.07–0.10 inches.

Test Objectives

The objective of this effort is to reduce the vulnerability of combat aircraft from a ballistically impacted burning munition and to obtain critical protection data on a full-scale weapons bay. Specific objectives included—

1. Further define the hazards of burning rocket motors inside a full-scale weapons bay

2. Formulate recommendations for ablative compounds to be used inside of the weapons bay

3. Test fire protection products and concepts against full-scale ballistically impacted burning munitions

The surrogate weapons bay (see Figure 1), is modular in nature, and able to accommodate remove/replace

Figure 1. Weapons bay simulator in China Lake's HIVAS facility.

Figure 2. Example of weapons bay test

ablative/intumescent panels. Figure 1 shows the fixture mounted in China Lake's High Velocity Airflow System (HIVAS) test facility. Airflow was directed along the bottom of the test fixture at 450 knots, no airflow was along the sides. The overall bay dimensions, approximately 24 by 24 by 160 inches, is representative of an average side weapons bay size for current fighter-type aircraft. The structure square tube is able to support missile thrust along the longitudinal axis as well as side forces. In test 1, the rocket motor was mounted to an F–102 trapeze that was protected with FASTBLOCK 800—however, in subsequent tests due to safety concerns, the rocket motor was mounted to the door. Two very small, micro-cameras were installed with one camera looking inside the weapons bay and the other viewing the aft end to witness any burn through. Additionally, there were titanium hydraulic lines, pressure transducers, thermocouples, and fire detectors installed within the test article.

Preliminary Test Results

Test 1

This test set-up was a mixture of protected aluminum and composite substrates with a titanium aft end piece. The titanium aft end piece was milled from one block of 1 inch plate stock. The web thickness, final plate thickness, and void spaces were averages obtained from an aft weapons bay bulkhead of a new aircraft. The surrogate titanium bulkhead was coated with MXBE–360, milled to 0.07 inch, and placed directly behind the rocket motor. A rocket motor was placed within the bay attached to the F–102 trapeze and ballistically impacted, immediately causing an ignition and burn. Upon rocket motor ignition, the bay overpressurized causing the door/actuator and forward top panel to fail. A pressure

Figure 3. Aft end bulkhead protected with MXBE–360 (Left–internal side, Right–external side).

wave of 48 pounds per square inch gauge (psig) hit the forward pressure transducer—however, the time duration, hence impulse, was small, but it was large enough to rip the forward top panel off the structure. This panel was held on by ten bolts, but not framed like the rest of the panels. Side panels bulged, but did not blow off the fixture. The rocket motor was allowed to burn for ten seconds prior to activating the trapeze and ejecting the item from the weapons bay. Due to the door and forward top panel failure, airflow entered forward end of the weapons bay. The aft panels received a considerable amount of rocket motor flame impingement. The highest temperature reading was 2,100º F on the side opposite the impact side of the rocket motor.

Test 2

In support of the Joint Strike Fighter (JSF) trade-off studies, safety issues, and results of Test 1, the configuration was slightly modified with a different door, door activation, thinner door panels, blow-out/burn-out panels, and a modified forward top panel frame. The rocket motor was mounted to the door instead of the F–102 trapeze. The main reasons for mounting to the door were safety concerns and structural uncertainties of the trapeze from the first test. The first test door skin was relatively thick and did not allow pressure and burn relief. Two infrared (IR) sensors were installed in the forward panel, one was protected with FASTBLOCK 301 and the other was unprotected. Upon impact with the rocket motor, an overpressure of 70 psig was witnessed on the forward pressure transducer—however, as in the first test, the time duration, hence impulse, was extremely small. All panels held and the rocket motor burned for 10 seconds prior to being lowered from the weapons bay. All panels received an incredible amount of flame, heat, and debris from the burning rocket motor. All thermocouples recorded temperatures in excess of 2,000º F. All materials protected the aluminum and composite substrates. Figure 2 is an example of the test. The white dots within the picture are a popped rivet and bullet hole, respectively.

Test 3

The configuration was the same as test 2. Side panels were protected aluminum and composite substrates. Rocket motor burn and door activation was the same as test 2. All panels received an incredible amount of flame, heat, and debris from the rocket motor. All panels survived but with varying degrees of heat damage. The ablative materials protected the substrates

Conclusions

During this first phase of testing the ablative materials performed exceptionally well. Although some materials performed better than others, the protection proof-of-concept for an internal rocket motor burn was substantiated for a ten second rocket motor burn. The rocket motor plumes are filled with molten aluminum particles and the environment is extremely severe. The aircraft designer must design the weapons bay to vent rocket motor exhaust, pressures, heat, and flame—otherwise, the reaction will find vulnerable areas, which will be detrimental to the aircraft. Of particular interest is the aft titanium substrate protected by MXBE–360 (see Figure 3). Based on previous laboratory scale sample tests, this was designed to fail at or near the ten second mark. The material was eroded to the substrate and the rocket motor began to locally soften the substrate just as the rocket motor was being ejected from the weapons bay. Other panels provided excellent protection for ten seconds and these will be taken into account in planning Phase II, which will investigate an extended burn. ■

Mr. Alex Kurtz received his B.S. in Aeronautical/Astronautical Engineering from Ohio State University. He is a research and test engineer for the 46th Test Wing, Wright-Patterson AFB, Ohio. He has been an aircraft survivability specialist for 17 years, working in vulnerability reduction research, Joint Live Fire Testing (JLF), congressionally mandated Live Fire Testing and Evaluation (LFT&E), Transport Aircraft Survivability Program, and various international programs. He is currently the Chairman of the Aircraft and Crew Protection Committee for the Joint Aircraft Survivability Program Office (JASPO) and the JLF USAF Deputy Test Director. He may be reached at alex.kurtz@wpafb.af.mil.

Mr. Martin Krammer received his B.S. in Mechanical Engineering in 1989 from California State University, Chico. He is a range and test engineer for the Weapons Survivability Laboratory, Naval Air Warfare Center Weapons Division China Lake, California. He has been supporting Live Fire Testing (LFT) and other survivability research testing for the past 14 years. He may be reached at krammermn@navair.navy.mil.

The Second Edition of the Survivability Textbook is Now Available

■ by Professor Robert E. Ball

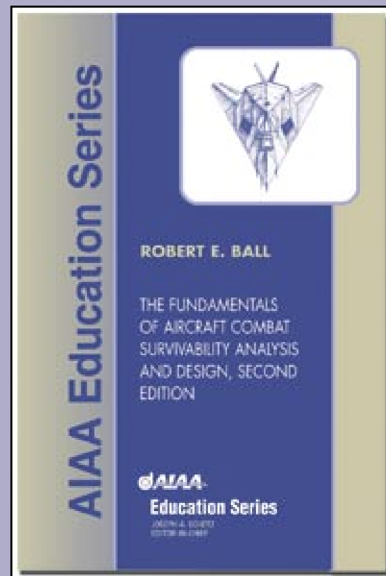
In 1985, the American Institute of Aeronautics and Astronautics (AIAA) published *The Fundamentals of Aircraft Combat Survivability Analysis and Design* as the fourth book in their new Educational Series. The world's first textbook on aircraft survivability was authored by Professor Robert E. Ball, Department of Aeronautics and Astronautics, Naval Postgraduate School, and funded by the JASPO (formerly JTCG/AS). The 400 page textbook became an overnight sensation. In the past 18 years, approximately 10,000 copies were sold, and the book was a perennial "best seller."

The JASP0 is now pleased to announce the publication by the AIAA of the 2nd edition of Professor Ball's textbook. From the Preface of the 2nd edition—

"This second edition is more than just an expansion of the 1985 textbook. It is now, truly, a student's textbook. It should also be more useful to the person who wants to learn what the discipline is all about. It has been rewritten into a form that should be useful to those who want to know only the essentials of the discipline (read Chapter 1), as well as to those who want to know all of the details (read the rest of the textbook). Large amounts of new material have been added throughout the textbook, and a new appendix on probability theory and its application to survivability assessment has been introduced. Learning objectives have been added at the beginning of each major section, and problems are now at the end of each section for those who are serious about learning the material. This second edition also provides the author with an opportunity to present information on the survivability features of several current U.S. military aircraft and some of the combat data from the Southeast Asia conflict and Operation Desert Storm. This information has only recently been released to the public."

The major sections of the over 900 page 2nd edition include the preface, prologue, acknowledgement, acronyms, an introduction to the Aircraft Combat Survivability discipline, aircraft anatomy, missions, threats, and threat effects, susceptibility (PH and PF), vulnerability (PK|H and PK|F), survivability (PS and PK), Survivability Features of several aircraft used in World War II, and Probability Theory and its application to survivability assessment. A separate Solutions Manual for the problems in the textbook is also available.

The book is now available. A hard copy, accompanied by a complete, searchable CD-ROM, can be purchased from the AIAA directly (http://www.aiaa.org/store/storeproductdetail.cfm?id=1008) at a cost of $99.95, or $69.95 for AIAA members, or from any bookstore or online book seller, such as Amazon.com. Government employees, both civilian and military, who have a need to know the information presented in the book may be able to obtain a copy at no cost from the JASPO by calling SURVIAC at 937.255.4840. ■



Survivability Textbook Second Edition

Recent Successes in Passive Fire Protection

■ by Mr. Joseph Manchor, Ms. Peggy Wagner, Dr. J. Mike Bennett, and Ms. Ginger Bennett

As previously reported in the Winter 2001/2002 edition of *Aircraft Survivability*, the Fuel Systems Committee of the Joint Aircraft Survivability Program Office (JASPO) is focused on enhancing the performance of passive fire protection technologies. This article reports on recent successes that have been achieved in three of these efforts "Reactive Powder Panels," "Ionomer Fuel Containment," and "Intumescent Instant Firewalls."

Reactive Powder Panels

This JASPO project investigated mechanisms to enhance the powder release from standard commercial fire protection powder panels. Standard powder panels utilize a fire suppressant powder encased within a brittle, honeycombed panel structure. The panel is normally affixed adjacent to a fuel source, such as the exterior surface of a fuel tank. Projectile impact is intended to cause breakup of the panel and release of the fire suppressant powder, thus preventing fire from follow-on projectile impact to the fuel source.

The JASPO project was initiated due to performance limitations observed in standard powder panels. Live fire testing of panels on current aircraft had shown that little powder might actually be released by ballistic impact. Because of this, standard powder panels are normally applied as a means of ignition mitigation, vice fire suppression. To be effective, they are normally combined with some other means of passive fire protection, such as self-sealing fuel cells, at considerable cost and weight penalty.

The JASPO enhancement concept utilizes a small amount of an energetic backing that is sandwiched between the standard powder panel and the structure to which it would be affixed. A strong shock, such as one from projectile impact, would cause the energetic to react, thus releasing most of the fire suppressant powder from the panel. Fiscal year 2001 testing of "reactive" powder panels demonstrated greatly improved powder release and dispersion in comparison to standard powder panels (see Figure 1).

Fiscal year 2002 work demonstrated the capability of the concept in extinguishing ballistically induced fires. The project was also expanded to allow leveraging with another government-sponsored effort to improve powder panel performance. This other effort had developed an "enhanced" powder panel under sponsorship of the Director of Defense Research & Engineering (OSD) (DDR&E) Next Generation Fire Suppression Program (NGP). The enhanced powder panel does not utilize energetic materials, but instead improves powder release through redesign of the panel's mechanical structure. More detailed information on enhanced powder panels may be found at http://fire.nist.gov/bfrlpubs/fire02/art104.html.

Comparison fire protection testing of these concepts was conducted in a simulator designed to approximate an internal aircraft void adjacent to a non self-sealing aluminum fuel tank. The powder panels were placed within the void and attached to the external surface of the fuel tank wall. A 12.7 mm armor piercing incendiary (API) projectile was then fired into each panel, and through the adjacent fuel tank filled with JP–8 jet fuel. A steel striker plate was also utilized for each test to ensure functioning of the projectile's

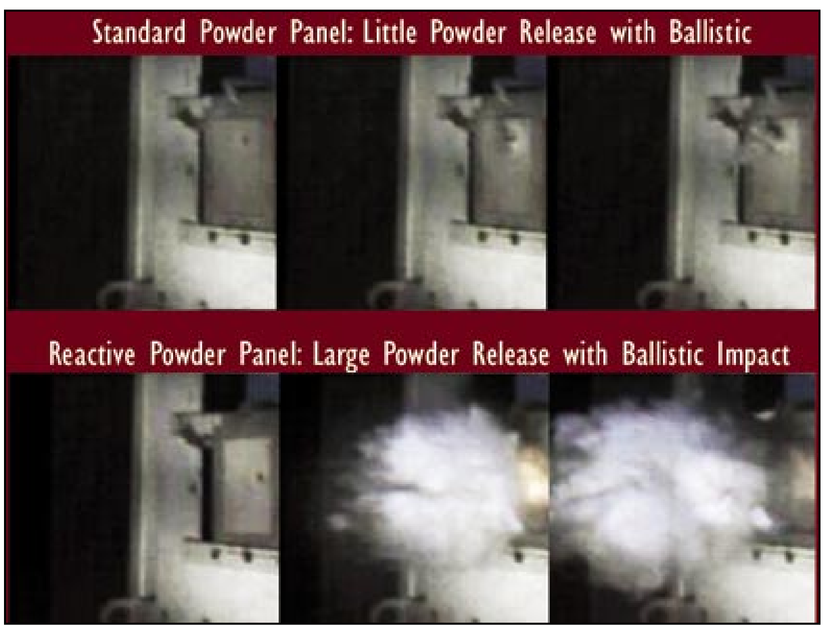


Figure 1. Standard powder panel (top), and with reactive backing (bottom)

incendiary close to the fuel tank wall, thus providing maximum challenge to the powder panel protection.

Figure 2 illustrates average results from testing. The standard powder panels were shown to be incapable of preventing fire from projectile impact within the simulator. Conversely, reactive powder panels provided a rapid and dense ejection of powder upon impact, thus preventing post-impact fires. The enhanced powder panels performed equally as well. Although ejection was not as rapid as the reactive panels, the non-energetic enhanced powder panels consistently released a dense cloud of suppressant powder upon impact, preventing any fire from occurring.

Following each test, the simulator interior was photographed to document powder dispersion. Little powder was noted on the simulator floor following standard powder panel testing. However, very good dispersion was noted following both reactive and enhanced powder panel tests. An even coating of powder was noted on the floor for these tests and was found to have effectively dispersed even behind hidden corners within the simulator. Figure 3 illustrates this dispersion.

In summary, both the "reactive" and the non-energetic "enhanced" powder panels showed dramatic improvement in fire protection performance over standard powder panels. This improvement is due to significantly greater powder discharge than provided by standard powder panels. Also, the improved panels provide far greater powder dispersion throughout the void to be protected. Effectively both of the new technologies provide for passive fire suppression, as compared to ignition mitigation as with standard powder panels.

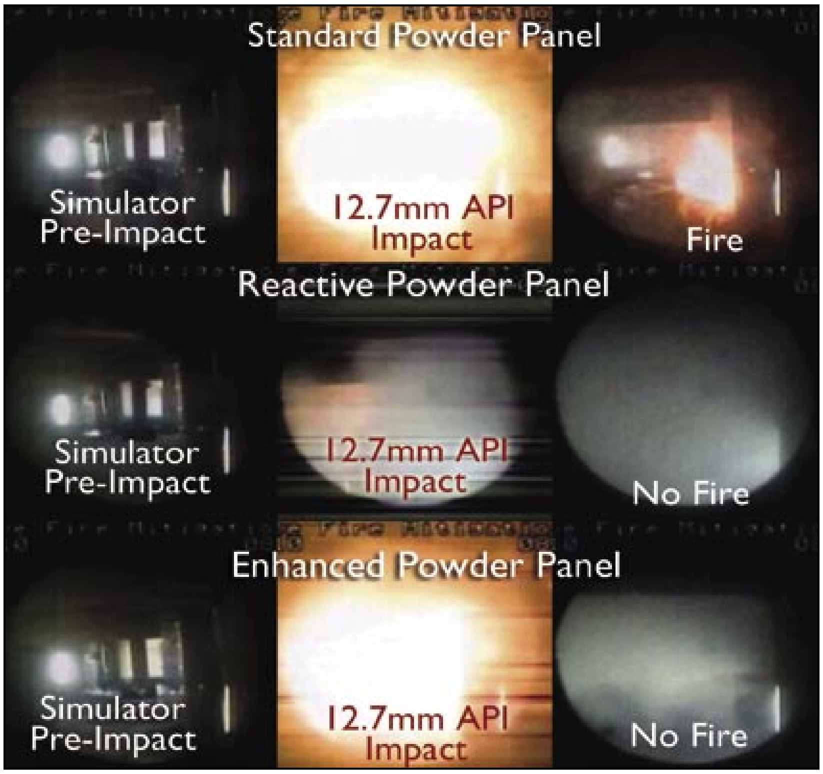


Figure 2. Standard, reactive, and enhanced powder panel performance (top to bottom)

Ionomer Fuel Containment

Current fuel containment self-sealing technologies have been relatively unchanged since World War II. The weight of an effective self-sealing system may be unacceptably heavy for some aircraft programs. Additionally, self-sealing does not occur instantaneously, and may take up to several minutes to achieve an effective seal, or may not seal at all. Under this JASPO project, the unique self-healing capabilities of ionomer plastics was investigated as a potential enhancement to fuel containment technologies.

Ionomer plastics are commonly used in many varied applications from food packaging, to car bumpers. An ionomer is a polymer plastic that contains ionic groups. These ionic groups are attracted to one another to provide a non-permanent cross-linking. Cross-linking is a mechanism that provides strength within a polymeric material. This mechanism may also contribute to a unique ability in some ionomer plastics to "self-heal" from ballistic damage.

This self-healing ability has already been exploited within industry as ionomer self-healing handgun targets are already marketed. Under JASPO sponsorship, ballistic testing of Surlyn® 8940 ionomer plastic was conducted to confirm the self-

Figure 3. Powder dispersion within simulator

healing properties of the material to anti-aircraft projectiles. Figure 4, and Figures 12 through 15 (see page 47) illustrates some examples of this healing for varied threat sizes and ionomer material thickness.

Ionomers were additionally evaluated to determine healing time, hydrodynamic ram resistance, and material properties. Observation of high-speed video impacts revealed that ionomer self-healing is extremely rapid, and occurs on the order of tenths of a millisecond. Testing also showed good resistance from hydrodynamic ram damage.

Material testing of ionomers was conducted under co-sponsorship of the Naval Air Combat Survivability Program (NACSP). This testing showed that ionomers degrade from prolonged and direct exposure to jet fuel. Over time, ionomers may absorb fuel and swell in thickness, similar to that which occurs to the natural rubber filler of self-sealing fuel cell material. As with self-sealing fuel cells, some type of fuel resistant barrier should be applied to the exposed surfaces of ionomers in fuel containment applications. Under JASPO sponsorship, several easily applied coatings have already been identified and tested that provide fuel protection to the ionomers, while minimizing weight impact. These coatings protect the ionomer until penetrated by a projectile. Upon penetration, fuel swelling of the ionomer may help to seal any residual cracks or holes in the material.

Future work will investigate several near-term ionomer survivability applications. These include the fabrication and ballistic testing of a lightweight small-arms resistant fuel tank for Unmanned Aerial Vehicle (UAV) applications. An ionomer fuel cell backing board will also be investigated. In addition to the structural fuel cell support, as provided by current backing board materials, an ionomer backing board would also serve as a secondary fuel containment barrier.

The rapid healing ability of an ionomer fuel cell backing board may also mitigate or eliminate the

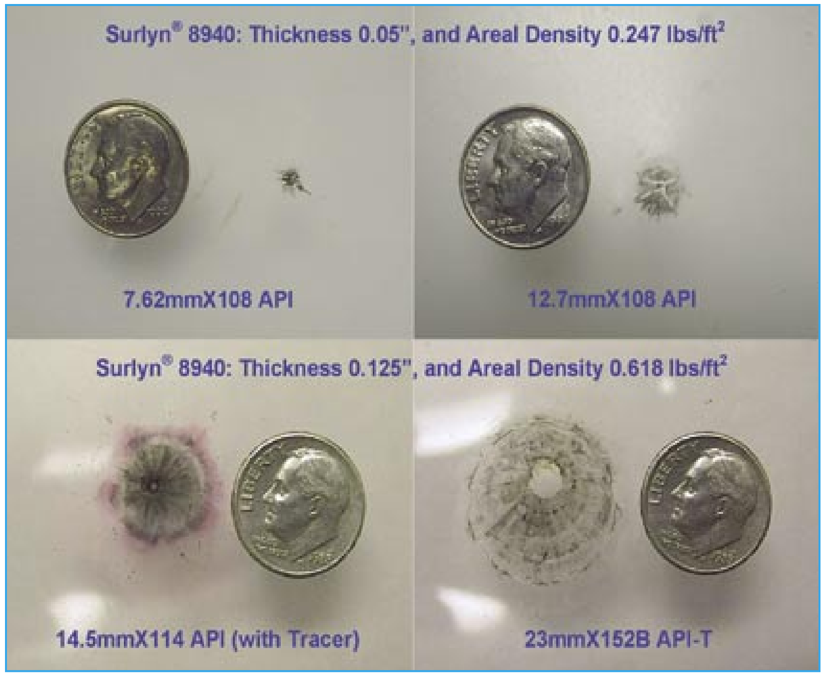


Figure 4. Ionomer self-healing to ballistic threats

hydrodynamic ram "quick dump" or "fuel spurt" phenomena. Ram quick-dump is a rapid ejection of fuel that occurs immediately after projectile impact to a fuel tank or fuel cell. It is caused by shock wave pressure rises that occur from projectile entry into the fuel. Although of short duration, it occurs within the timeframe and vicinity of armor piercing incendiary (API) incendiary function, and is often the source of fuel ignition of ballistic dry bay fires. Hence, the mitigation of quick-dump may likewise mitigate the potential for fuel ignition and fire from API ballistic impact.

Intumescent Instant Firewalls

Another technology sponsored by JASPO pertains to the concept of using intumescent materials in special configurations to form "instant firewalls" to control, contain, and manage fires in normally ventilated aircraft compartments. This lightweight, affordable passive technology, which like the aforementioned products requires no aircraft power or electronics to function, offers a potentially ideal solution for many cost conscious platforms, such as the Joint Strike Fighter and various UCAV variants—particularly those which do not currently have (or are not required to have) on-board fire extinguishing systems. This technology can also improve the performance of conventional extinguishing systems actually used in such compartments. The current JASPO investigation underway, which entails developing, refining and demonstrating variants of the concept in intermediate and full-scale engine nacelle tests, will build on the results of a previous exploratory study of the concept performed for the Next Generation Fire Suppression Technology Program (NGP).

Aircraft engine nacelles have fluid lines that are routed within the enclosure on the exterior of the engine core or related components to provide fuel, oil, or hydraulic fluid to the propulsion system (all of which are typically flammable). These nacelles are generally ventilated by free stream exterior airflow directed inside various inlets and into the nacelle, to prevent the accumulation of any flammable vapors, and to provide some cooling, before the airflow exits via one or more outlets. In a typical fire scenario, a fluid line may leak (e.g., ballistic damage) and spray or stream the flammable fluid onto the hot components, which results in a fire. The ventilation airflow continues to support the fire, and directs the orientation of the resultant flame region downstream. An automatic extinguishing system may be discharged

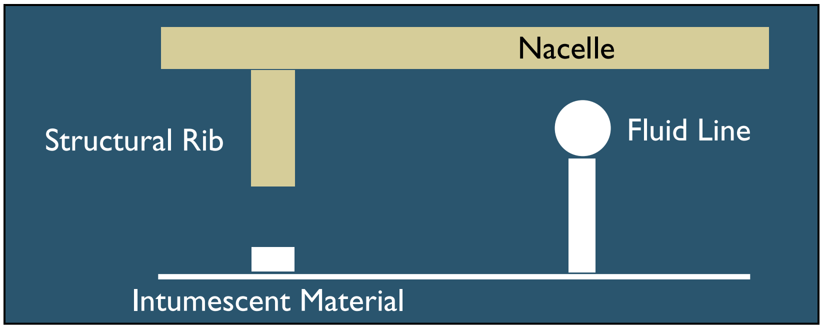


Figure 5. Cross section view of region between nacelle and engine

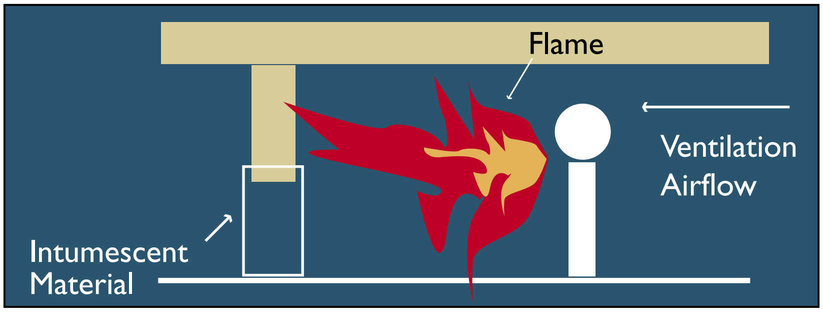


Figure 6. Fluid leak and subsequent fire

from upstream to apply the extinguishing agent to the fire, but due to rapid dilution by the ventilation airflow and short residence time near the fire (and robustness of a bluff-body stabilized flame), many of these fires will not be extinguished with agent quantities desirable for many of these applications, with little of the discharged extinguishant effectively used. Another concern is that the fire may re-ignite due to the flammable fluid continuing to flow onto the hot surface with replenished airflow after the extinguishant has been drawn downstream. Because of these challenges, current engine nacelle applications have serious problems with fire events, and extinguishing techniques only have limited success, or require extinguishing quantities and hardware that are impractical or undesirable because of size and weight.

Many aircraft currently use firewalls at some location adjacent to engine nacelles to prevent fire propagation away from the engine. Unfortunately, these locations are usually limited to areas like the engine pylon (if the engine is mounted away from the aircraft body or wing), because it is desired to avoid constriction of the ventilation airflow directly around the engine under normal operating conditions. Such firewalls can also be heavy, and are only needed when an actual fire occurs, and near the site of the fire. The intumescent material design described here could provide such protection by swelling when heated and "instantly" forming a lightweight fire barrier at the location of the fire, without impeding the normal flow of air during regular operations.

Intumescence may be defined as "thermally induced expansion of a material." The popping of corn, the expansion of perlite and vermiculite, the puffing of wheat, rice, and other grain cereals are common examples of intumescence. The pyrotechnic "snake" (fireworks) is another familiar example. It is a mixture of sugar, oxidizer, and certain fuels which generate a carbon char of highly expansive, voluminous, and friable nature. The mechanism of intumescence may be described as the rapid release of gas or vapor from a matrix which, upon rapid heating, undergoes a plastic or viscoelastic transformation which permits it to be expanded, inflated, or dilated by the expanding vapor or gas. Intumescent materials come in several different forms that include coating/paint, tape, caulk/sealant, and putty. The expanded char thickness may range from between 2 and 80 times that of the original material and result in an expansion amount of between 1–30 inches. The char thickness can be characterized by either high (>15x), moderate (3x to 15x), or low (<3x) volume expansion. Intumescent coatings typically activate in a temperature range of 270 to 500°F. Intumescent coatings have been used in industry (including the military) for years, as coatings for critical structures to prevent thermal weakening when exposed to fire. Another relevant application is their use as a "fire block" around the exterior of pipes that extend through walls in construction, to swell and seal off clearance holes to prevent the migration of fire from one compartment to another. The challenge in this new application is to use the materials in a ventilated space to block off airflow, yet withstand the stresses the flow imparts to remain intact during sealing.

The intumescent coating can be applied in a number of ways—as a very narrow and thin strip, in a form of one or more closed rings on the exterior of the engine case or components, or nacelle skin interior. In each of these applications, the intumescent coating is located to swell against opposing surfaces in the nacelle at locations where clearance is minimal such as opposing structural ribs, (see Figure 5).

If a fire occurs in an engine nacelle, (see Figure 6) the resulting flame would impinge upon a portion of the intumescent material strip, which would normally swell several orders of magnitude beyond its original thickness upon heating. This swelling would block off the downstream airflow path by sealing against opposing surfaces in the vicinity of the fire, depriving it of a steady flow of fresh air and creating an oxygen-deprived stagnation region, thereby facilitating self-extinguishment.

If the blockage is only partial, and the flame follows the re-directed airflow around the sealed-off area, the local intumescent-covered portion in that new region would also swell since the strips extend around the engine perimeter as contiguous rings. This would eventually seal off the perim-

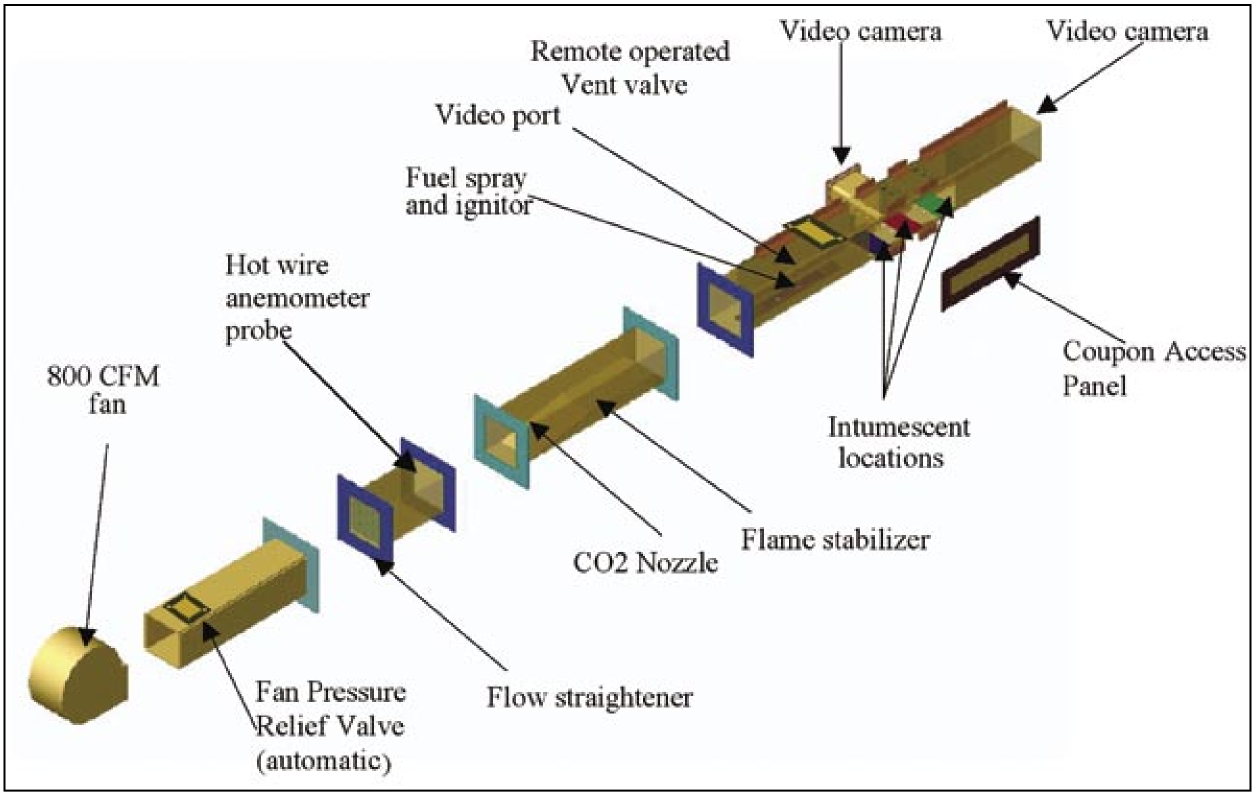


Figure 7. Test Article Schematic

eter of the machinery space, creating a stagnation zone and depriving air and oxygen flow to the fire until it self-extinguishes (without any use of extinguishant), or contain and suppress the fire until it can be addressed after landing. In this manner, a series of "firewalls" can be formed using a minimal quantity of intumescent. If an extinguishing system is also used, it can improve its effectiveness or permit smaller systems by weakening the fire and reducing the airflow dilution and leakage of the extinguishant, and permit its residence in the vicinity of fire for an extended period until extinguishment is complete. The intumescent coating may only be needed in a limited region of the compartment, where the origin of fires is most likely. If the gap is relatively large between the engine/component surfaces and the nacelle, then a strip may be placed on both the nacelle and engine surfaces, which upon expansion could meet in the middle, or other configurations to optimize the expansion and durability of the expanded material.

The potential benefits of incorporating such a technology if correctly used can be significant, considering the estimated weight impacts of a realistic configuration. A strip 0.5 inches in width, 0.12 inches thick (to seal up a clearance gap of two inches or more) spread around an engine core 36 inches in diameter (which would represent an fighter type engine), would result in a weight increase of only 0.23 pound per ring. Even if four rings were used at various locations along the engine core, then a total weight of only 0.92 pound would be added. This weight is minimal in comparison to the size of extinguisher systems that are currently used, which can range from 10–20 pounds total weight per engine. Estimates of extinguishant weight savings by minimizing leakage (by comparing a "total flood" application sizing criteria with minimal leakage versus use of the sizing criteria assuming normal ventilation dilution) is also significant, with up to 50 percent weight savings or more.

A multi-phase JASPO program is currently underway at the 46 OG/OGM/OL–AC at Wright Patterson AFB, Ohio, to realistically evaluate the merits of this concept for aircraft compartment use in this manner. This program is addressing the key issues that must be considered for this application in intermediate and large-scale fire tests, in addition to modifying various embodiments to improve its overall performance. Several key issues to be addressed include—

- Assessing the strip widths and thicknesses necessary to achieve adequate expansion within a reasonable time (a minute or less)
- Assessing the merits of a large number of material candidates for this configuration, including the maximum expansion heights possible at any original thickness
- Determining each candidate and configuration's ability to resist shearing forces applied by the air flow as it seals up the opening
- The minimum distance a strip must be from a flame origin to function (which affects the number of strips needed)

Phase I of this test program is complete. Data was collected to characterize the performance of the intumescent materials as a firewall in a simulated aircraft engine nacelle environment. 79 companies were

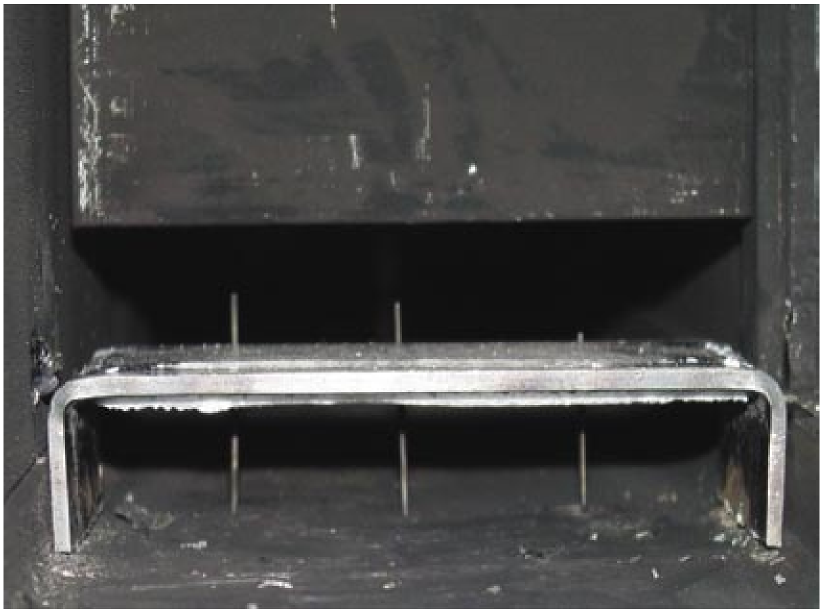


Figure 8. Coupon "bridge" configuration

Figure 9. Coupon "bridge" configuration after activation

contacted and asked to provide intumescent materials and five samples were submitted. Preliminary tests examined these five and identified two candidates (Contego and FX100) to explore further in the nacelle simulator.

A spray fire scenario was created to simulate a ruptured or leaking fuel line within the nacelle where flammable fluid can leak onto the hot engine case or accessory components and ignite. An eight percent sector of a typical aircraft engine nacelle was designed and fabricated for this effort. The generic nacelle has dimensions of 48 inch outer diameter and 42 inch engine core diameter, for a 6 inch nacelle free space with clutter. Considering test costs, and given that the purpose of the testing was to evaluate the feasibility of using intumescent material as a fire stop, a segment of the annular space was considered to be adequate. A simple square tubing provided an inexpensive approach to simulation of a segment of the annular space. Width was not considered to be a critical factor in the feasibility evaluation. The vertical height was the main set up configuration. The inside dimensions of a 6" x 6" box beam is slightly less than 6 inches per inside dimension. The eight percentage is a nominal value of the ratio of the volume of the annular space between 48–42 inch diameters and the inside of the box beam.

A single test article was used during this test program (see Figure 7). The test article represented an eight percent sector of an aircraft engine nacelle. The test article was constructed out of 0.125 inch thick steel. The overall dimensions of test article are 6" x 6" x 10'. A variable controlled 800 CFM fan was used to provide the appropriate airflow. A flow straightener was used to reduce the turbulence of the airflow. A backward facing step (bluff body) was used to create a recirculation zone. A JP–8 fuel spray (400 psi) and ignitor were placed downstream of the bluff body to create the fire scenario. A thermocouple grid was used to measure the temperature in the intumescent location area. Two widths of intumescent material and two coating thicknesses were evaluated. The parameters and settings used in this test series are shown in Table 1 (see page 47).

Three intumescent application/configuration methods were examined—

- On a flat coupon placed on the simulated engine core
- Suspended with intumescent material placed on the top of and below the coupon "bridge" (see Figure 8)
- On a wire mesh (see Figure 10)

Test data included the intumescent material, activation temperature, ability to withstand airflow, original width required to withstand the shear forces of the airflow after the material has expanded, original and expanded height, and the resulting percent sealed of the opening.

The intumescent material FX100 proved extremely successful with the "bridge" application/configuration in starving the fire (see Figure 9). The intumescent expanded to meet the rib within the simulator and began closing off the nacelle opening causing a backpressure. The swelling began within 20 seconds and sufficiently closed off the nacelle area in 50 seconds total. The Contego material performed poorly under the same conditions.

Both materials were also tested using the wire mesh application/

configuration with two different inside dimensions of the mesh. In this application/configuration, the Contego was highly successful in growing in to meet in the center of each cell and suppress the fire (see Figure 11). The FX100 performed poorly.

Neither material was successful in expanding to the height needed when the flat plate application/configuration was utilized.

Results of the Phase I testing were highly successful in demonstrating the concept of using intumescent materials as an "instant firewall." Further testing is required to better define the various parameters (e.g., coupon thickness, size of wire mesh) as well as testing in a platform specific configuration.

Three promising passive fire protection technologies have been described in the previous pages. Each has been shown to have the potential to significantly improve fire protection on current and

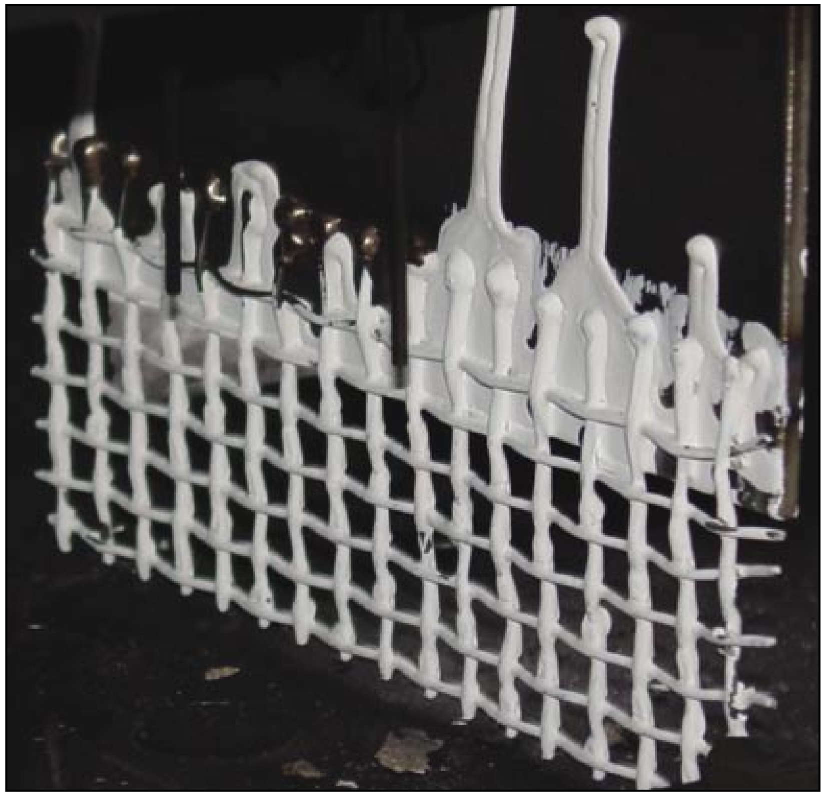


Figure 10. Wire mesh configuration

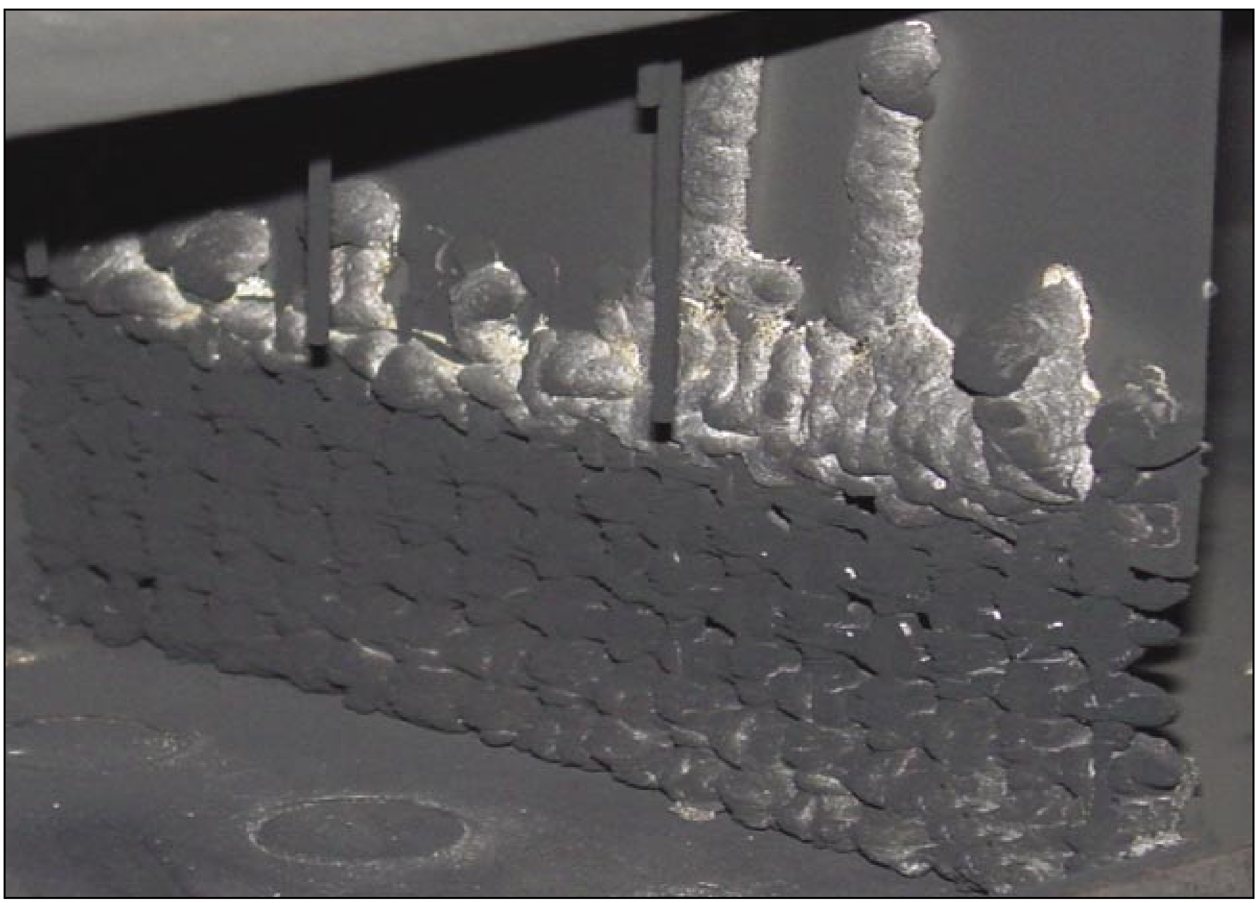


Figure 11. Wire mesh configuration after activation

future aircraft. However, to realize the potential of these technologies, additional testing is required. This testing will better define the different parameters involved in the various technologies. Furthermore, testing needs to be done on a more platform-specific test configuration to determine the performance of each of these technologies. Ultimately, cost/benefit analyses will need to be conducted to determine the true value of each over the complete life cycle of a platform. ■

Figure 12. Test 20 Ply 1 Front

Figure 13. Test 20 Ply 1 Front Backside

Figure 14. Test 20 Ply 2 Rear Front

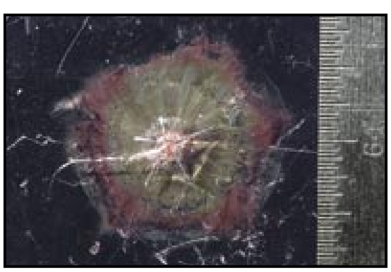


Figure 15. Test 20 Ply 2 Rear Backside

Parameter	Symbol	Low Setting	High Setting
Airflow	Air	67 CFM	135 CFM
Intumescent Location	Loc	Upstream	Downstream
Rib Height	Rib	4 in	2 in
Width of Intumescent	Width	1 in	3 in
Height of Intumescent	Height	0.0625 in	0.5 in

Table 1. Parameters and settings

Mr. Manchor is an aircraft vulnerability reduction engineer at the U.S. Naval Air Warfare Center Weapons Division (NAWCWD), China Lake, California. He has conducted numerous live fire ballistic tests of naval aircraft, and provided subsequent recommendations to reduce the vulnerability of these aircraft based on the results of testing. With a specialty in aircraft fire and explosion protection, he oversees and conducts research and development efforts in this field. He serves as co-chairman of the Fuel Systems Committee of the Joint Aircraft Survivability Program Office (JASPO). He holds a M.S. in Mechanical Engineering from the Pennsylvania State University), and a B.S. in Aerospace Engineering from the United States Naval Academy. He may be reached at joseph.manchor@navy.mil.

Ms. Wagner is an aerospace engineer with the 46th Test Wing's Aerospace Survivability and Safety Flight at Wright-Patterson AFB, Ohio. She has extensive experience in the aerospace survivability/vulnerability area including aerospace vehicle survivability design, vulnerability testing and assessment, modeling and simulation development and analyses. Ms. Wagner has a BS in Systems Engineering from Wright State University and a M.S. in Systems Engineering from The Air Force Institute of Technology (AFIT). She may be reached at peggy.wagner@wpafb.af.mil.

Dr. J. Michael Bennett, Ph.D. has served in the field of aircraft survivability, and fire and explosion protection in particular, for sixteen years. He received his Bachelor's and Master's degrees in Mechanical Engineering from the University of Louisville, and his Ph.D. in Mechanical Engineering from the University of Dayton, specializing in combustion He served for over fifteen years in the Air Force Research Laboratory and 46th Test Wing, and served as the Team Leader of the Fire Protection Team. Although his responsibilities included fuel tank, dry bay, engine and related fuel system protection, he is particularly known for his work in developing environmentally acceptable replacements for Halon fire extinguishants, including the initiation of gas generator fire extinguisher technology exploitation (which has been subsequently put into service on several aircraft). He may be reached at jmichaelbennett@yahoo.com.

Ms. Ginger Bennett is an Associate with Booz Allen Hamilton. Booz Allen Hamilton is a strategy and technology consulting firm with over 90 offices and approximately 11,000 staff worldwide. Booz Allen operates the Survivability/Vulnerability Information Analysis Center in Dayton, Ohio. Ms. Bennett received a BS and MS in Mechanical Engineering with a concentration in the areas of biomedical engineering and biomechanics from The University of Alabama. Ms. Bennett's major technical experience has been in aircraft fire protection. She may be reached at bennett_ginger@bah.com.

USNA Mids Face Off in Survivability Exercise

■ by JO1 Jennifer L. Wuest

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On April 9th, NAVAIR's Survivability Division (AIR–4.1.8) hosted 20 Midshipmen from the U.S. Naval Academy's Aircraft Survivability course (EA486C), taught by Dr. Larry Birckelbaw. These students, accompanied by CAPT Robert Niewoehner (Ph.D., Chairman, Aerospace Engineering, USNA) and Jim Young (Vulnerability Branch Head, NAVAIR), were treated to a full day of tours at Patuxent River Naval Air Station (NAS), including the Air Combat Environment Test and Evaluation Facility (ACETEF), the Atlantic Test Range, and aircraft including the V–22, AH–1Z Cobra, UH–1Y Huey, KC–130J, MH–60R, MH–60S, CH–53E, and F/A–18E/F. However, the marquee event involved a survivability team project competition at Patuxent River, Maryland.

The Survivability Division oversees a variety of technologies and their application to Naval Aviation. Survivability is divided into two disciplines—susceptibility and vulnerability. Susceptibility technologies enable a platform to avoid detection and interception by a threat. These encompass stealth technologies, and involve platform signature reduction in acoustic, radar cross-section (RCS), infrared, and visual frequency spectrums. Vulnerability technologies enable a platform to survive after "being hit" by a threat. These technologies include fire suppression, critical component redundancy, armor, explosion suppression, and many others. A platform equipped with susceptibility and vulnerability reduction technologies provides the warfighter with a greater probability of survival and mission success in a hostile environment than a platform without.

Survivability Division members have recently presented susceptibility and vulnerability briefs to the class, supplementing course material with practical Naval applications and design experience. The Survivability Division challenged the class to participate in a survivability team competition as an exercise. Working in teams of four, the exercise required each team to design and build a structure that would improve the survivability of a soda can, when hypothetically flown in a fictional threat environment. Teams competed for points awarded for performance in five key design areas—volume, radar cross-section (RCS), weight, vulnerability reduction, and crash worthiness.

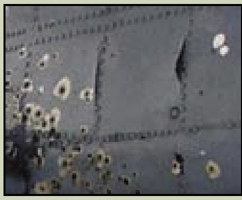
After all projects passed the design volume criteria, they then underwent X-band RCS testing in the RF Sensor Division's Small Anechoic Chamber, and were ranked in order of lowest RCS achieved in three frontal sectors. Next, all projects were weighed and ranked from lightest to heaviest. Vulnerability testing followed and this challenge consisted of withstanding an impact in the rear sector from mock projectile, which slid down a 10 foot pipe at a 45 degree angle. Points were awarded and based on the degree of damage suffered by the soda can. One project suffered a soda can leak and was eliminated from further competition. The final test for the remaining projects was to survive an 8 foot drop test. Again, points were awarded and based on the degree of damage suffered by the soda can. One project suffered a large dent in their soda can, but it did not leak. When the dust settled, the teams of "Front Row" and "Shockers" emerged as co-winners of the challenge.

All five projects exhibited a balance of design trades. One team went so far as to construct their project using fiberglass, and then coating it with nickel paint. This allowed them to incorporate curved surfaces in their design, reducing RCS scattering from edges and tips. Another team incorporated Kevlar in their design for vulnerability reduction. Ken Goff (Survivability Division Head) commented—

"It is apparent to me that all five teams went to great lengths to succeed in this competition, and as a result, they have gained more knowledge and insight into survivability issues than they would have otherwise."

The Aerospace Engineering Department at the U.S. Naval Academy graduates approximately 60 students annually, most of who go into Naval Aviation as Navy/USMC pilots and Naval Flight Officers (NFOs). Years later in their careers, many subsequently pass through Pax River as test pilots or in program billets. The Aircraft Survivability course arose this year as an experimental elective offering, principally because of the availability of Dr. Birckelbaw as a Defense Advanced Research Projects Agency (DARPA) Visiting Professor. His background with integrating survivability technologies into four X-planes at NASA and DARPA provided the requisite skill base to offer the course. The modern prominence of survivability in the design of modern aircraft (civilian and military) elevates the discipline to a role approaching that of the traditional pillars (aerodynamics, stability and control, propulsion and structures). As USNA Midshipmen enter the fleet and then into roles as engineers and program managers of Naval Aviation, understanding survivability technologies enhances their professional knowledge of their craft as operators and acquisition professionals for future Naval Aviation weapon systems. ■

Figure 1. U.S. Naval Academy Midshipmen look on as class projects undergo testing at Patuxent River, Maryland, in a friendly competition hosted by the Survivability Division.



Pilot Brings Battle-Damaged A–10 Home Safely

■ by Staff Sgt. Jason Haag

Reprinted with permission of the Air Combat Command News Service.

Editor's Note: *The JASPO (formerly JTCG/AS) and a number of its members contributed to the battlefield success of the A–10. Jerry Wallick, Capt. Joe Pharmer, Gerry Bennett, Don Voyls, Andy Holten, Charlie Anderson, Charlie Gebhart, Levelle Mahood, and Dale Atkinson, all with the Air Force at the time, played a major role in the survivability design and live fire testing of the A–10, along with Joe Arrighi and Dick Mott from Fairchild. JASPO developed vulnerability reduction technology, survivability design techniques, and live fire test techniques were used in the design and testing of the aircraft. Major live fire test programs were carried out in the late 1960s and early 1970s at what is now called the U.S. Air Force Survivability Research Test Facility in support of both the A–9/A–10 Fly Off (i.e., during the AX competitive prototype phase or CPP) and the development, test and evaluation (DT&E) phase. As a result, the A–10 was one of the first aircraft to have survivability designed in and then evaluated during a live fire test program from the very beginning of the design and acquisition process. The survivability of our aircraft and the ability to bring back our warfighters have been goals of the JTCG/AS (now JASPO) since its inception and it is rewarding to see that it continues to pay off in saving lives and aircraft in combat.*

Captain Kim Campbell, deployed from the 75th Fighter Squadron at Pope Air Force Base, North Carolina, and her flight leader had just finished supporting ground troops and were on their way out of the area when her aircraft was hit with enemy fire.

"We were very aware that it was a high-threat environment—we're over Baghdad. At the same time, those are the risks you are going to take to help the guys on the ground, that's our job, that's what we do. Our guys were taking fire and you want to do everything you can to help them out. We did our job with the guys there on the ground and as we were on our way out is when I felt the jet get hit. It was pretty obvious—it was loud."

Captain Campbell said. After sustaining the hit, she said the aircraft immediately became uncontrollable and she noticed several caution warnings—all over a very hostile territory.

"I lost all hydraulics instantaneously, so I completely lost control of the jet. It rolled left and pointed toward the ground, which was an uncomfortable feeling over Baghdad. The entire caution panel lit up and the jet wasn't responding to any of my control inputs."

Captain Campbell tried several different procedures to get the aircraft under control, none of which worked, she said. At that point, she decided to put the plane into manual reversion, which meant she was flying the aircraft without hydraulics. After that, the aircraft immediately began responding. "The jet started climbing away from the ground, which was a good feeling because there is no way I wanted to eject over Baghdad," she said. Because the aircraft sustained hits to the rear of the aircraft, including the horizontal stabilizer, tail section and engine cowling, Captain Campbell said she could not see the damage. Her flight leader, Lt Col Richard Turner, positioned his aircraft where he could view the damage.

"The jet was flying pretty good and the damage had not affected the flight control surfaces or the (landing) gear," Colonel Turner said. "If (Kim) could keep it flying, we would get out of Baghdad and might be able to make it (back to base).

Once they assessed the situation, the two worked closely together to determine the best course of action. Captain Campbell said the colonel's calm demeanor and attention to detail were instrumental in her being able get the airplane home.

"I could not have asked for a better flight lead," she said. "He was very directive when he needed to be, because all I could concentrate on was flying the jet. Then, once we were out of the Baghdad area, (he) just went through all the checklists, all the possibilities, all the things I needed to take into account."

Captain Campbell said she and Colonel Turner discussed all her options, which ultimately came down to two—fly the aircraft to a safe area and eject or attempt to land the disabled plane.

"I can either try to land a jet that is broken, or I can eject...which I really didn't have any interest in doing, but I knew it was something that I had to consider," she said. "But the jet worked as advertised and that is a

tribute to our maintainers and the guys who work on the jet. It's nice when things work as advertised." Colonel Turner said that even though he could advise her, only one person could make the decision about whether to eject or attempt to land the aircraft. "She had a big decision to make," he said. "Before anyone else could throw their two-cents worth into the mix, I made sure that she knew that the decision to land or eject was hers and hers alone."

To Captain Campbell, the decision was clear. "The jet was performing exceptionally well," she said. "I had no doubt in my mind I was going to land that airplane." After getting the aircraft on the ground, the final task was getting it stopped and keeping it on the runway, she said—

"When you lose all the hydraulics, you don't have speed brakes, you don't have brakes and you don't have steering," she said. "One of the really cool things that happened when I did touch down, I heard several comments on the radio—and I don't know who it was—but I heard things like, 'Awesome job, great landing,' things like that," she said. "I guess we all think we are invincible and it won't happen to us," she said. "I hadn't been shot at—at all—in all of my other missions. This was the first. Thank God for the Warthog, because it took some damage but it got me home." ■

Figure 1. Capt Kim Campbell, an A–10 Thunderbolt II pilot deployed with the 332nd Air Expeditionary Wing, surveys the battle damage on her airplane. The A–10 can survive direct hits from armor-piercing and high projectiles up to 23 mm. Manual systems back up their redundant hydraulic flight-control systems. This permits pilots, like Capt Campbell, to fly and land when hydraulic power is lost.

Calendar of Events

OCT

13–16, Dayton, OH
National Conference on the Advancement of Research (NCAR) from Technology Breakthroughs to Technology Revolutions
www.ncar.org

21–23, U. of Washington
Passive and Covart Radar Conference
www.crows.org

21–23, Nellis AFB, NV
Joint Aircraft Survivability Program Office
Integrated Program Review
Jennifer Willie 703.607.3509, ext. 10
jennifer.willie@navy.mil
http://jas.jcs.mil

28–31, Woborn, MA
Aircraft Fires and Explosions–Due to Accidents, Combat, and Terrorist Attack
Albert Mousa 617.661.0700
www.blazetech.com

NOV

3–6, Monterey, CA
Aircraft Survivability Symposium 2003
Aircraft Combat Survivability in the Low-Altitude Battlespace
jhylan@ndia.org
www.ndia.org

3–7, Dayton, OH
Aircraft Fire and Protection/ Mishap Investigation Course
937.435.8778
http://members.aol.com/afp1fire/www.htm

3–7, Santa Clara, CA
ISTFA 2003 International Symposium for Testing and Failure Analysis
613.824.2468

17–20, Palm Springs, CA
41st Annual Air Targets, UAVs, and Range Operations
asaliski@ndia.org

18–20, Nellis AFB, NV
Brawler and ESAMS Users Group Meeting
jeng_paul@bah.com

DEC

8–11, Las Cruces, NM
International Test and Evaluation Association Modeling and Simulation Workshop
www.itea.org

JAN

5–8, Reno, NV
42nd AIAA Aerospace Sciences Conference and Expo
www.aiaa.org

26–29, Los Angeles, CA
Annual Reliability and Maintainability Symposium (RAMS)
Dr. William Robertson
703.550.9436

Information for inclusion in the Calendar of Events may be sent to:

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